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The Safety-Cost Relationship for Certain Types of Surface and Trench Shelters

A Joint Home Office and
Ministry of Works Study

HOME OFFICE
SCIENTIFIC ADVISERS' BRANCH
WHITEHALL, S.W.1

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(Summaries of these tables are included in the text as necessary).

THE SAFETY/COST RELATIONSHIP FOR CERTAIN DESIGNS OF SURFACE AND TRENCH SHELTERS

Summary and Conclusions

This study was made as a step towards a shelter policy which would enable a maximum of protection to be provided in areas considered liable to atomic attack as quickly as possible and at a minimum cost of labour and materials. It was confined to reinforced concrete surface and trench shelters, leaving other forms of shelter, in particular Anderson and basement shelters, for subsequent consideration. However, weapon development has proceeded at a pace far exceeding what was regarded as probable a year ago, and the study is now likely to be of little more than academic interest. Nevertheless it seems desirable to place the results of the work on record. Indeed it may serve as a stepping stone to studies more appropriate to present circumstances.

Assumptions made

This study has been made on the basis that the predominant danger is that of atomic attack, though H.E. attack cannot be ignored. It has been based on atomic attack by means of nominal (20 kiloton) atomic bombs burst at ground level or any height up to 3/8ths of a mile, and for working purposes it has been assumed that the bombs will take full effect over an area of uniform population density, and that the risk of attack is the same in all areas where shelters are provided. Consideration has however been given to the extent to which these working hypotheses limit the value of the conclusions reached, including in particular the effect of the use of larger bombs.

Introduction of Safety and Safety/Cost Ratings

Series of designs of surface and trench shelters have been studied and two new conceptions - a "safety rating" and a "safety/cost" rating - have been adopted for comparison of one design with another.

(a) If all the population of an area affected by air attack (atomic or H.E.) are in ordinary houses, a certain number of deaths will be expected from a specified attack. If they are all in shelters of a given design, the expected number of deaths will be smaller. This saving of lives, expressed as a percentage of the deaths if all are in houses, is defined as the safety rating of the shelter against the attack specified. Thus the safety rating scale runs from zero for houses up to 100 for completely bomb proof shelters. If the population were greater or smaller, the number of deaths expected if all were in houses, and the number expected if all were in the shelters, would go up or down in the same proportion, and the safety rating is not therefore dependent on the population density, except in so far as an even spread of population is assumed.

(b) The safety/cost rating is arrived at by dividing the safety rating by the estimated cost per head of the shelter, on the basis of seated accommodation and is considered to be the best available measure of the speed with which lives can be saved by the adoption of one design or another.

Surface shelters

Sixteen designs are studied of a reinforced concrete surface shelter 35ft. long by 7ft. wide, giving seating accommodation for 50 persons. The designs have thicknesses of 12, 15, 18 and 24 ins. and strengths of 250, 500, 1000 and 1400 lb/sq.ft.

Shielding from gamma radiation

The effects of shielding from gamma radiation by surrounding buildings are found to have a very large influence on the number of deaths caused in these shelters, and each design is studied in relation to three conditions of shielding, i.e. unshielded, moderately shielded and well shielded. Broadly speaking, the best shielding will be found in narrow streets with tall buildings on either side, such as are found in a city centre, and a fair degree of shielding will be found in wider streets with terraces of houses on either side. The governing factor will normally be the slope of the line from the floor of the shelter to the roofs of the buildings on the further side of the street. The following were taken as typical measurements:-

Good shielding. Buildings 50 ft. high and 20 ft. away.

Moderate shielding. Buildings 20 ft. high and 30 ft. away.

These heights and distances give shielding angles of 68° and 34° respectively.

Combination of the blast and radiation hazards to calculate deaths. For each design and for each shielding condition total deaths due to the combined effects of blast and radiation are calculated for a nominal atomic bomb on average for different heights of burst between ground level and 3/8ths mile and for the effect of the orientation of the shelter relative to the bomb (i.e. side-on or end-on).

Development of the "optimum" shelter. The cost of each design is estimated and curves are drawn showing the relationship between cost and safety rating for each design and for each degree of shielding. These curves are drawn in such a way that the most efficient strength for each concrete thickness and for each degree of shielding can be deduced.

It is shown that for each degree of shielding there is a single combination of strength and thickness which gives the best safety/cost rating. The optimum thicknesses are found to be for open sites 18 ins., for moderate shielding 15 ins. and for good shielding 12 ins. All the optimum designs call for a strength of 1400 lb/sq.ft. This was the greatest strength studied, and an extension of the study to shelters of rather greater strength might show them to give a slightly higher safety/cost rating.

It is shown also that on the assumptions mentioned above it can never pay to build shelters of less than the optimum strength or thickness. Even if limitations of time or resources prevent the programme from being completed, more lives would be saved by providing as many as possible of the inhabitants with optimum shelter, and leaving the rest without shelter, than by building a lower standard of shelter for everyone.

The addition of earth or sand-bags to the roof. The possibilities of improving the radiation protection of a shelter by piling earth or sand-bags on the roof are investigated and it is concluded that the safety/cost rating for the optimum design of moderately shielded shelter (15"/1400 lb/sq.ft.) could probably be improved somewhat by the addition of about 10 ins. of earth on the roof. A reduction in roof concrete thickness to 6 or 8 ins. compensated for by an increase to about 18 ins. in the earth might still further improve the safety/cost rating. However the improvement could not be large and would be dependent on the possibilities of designing a thinner slab to resist 1400 lb/sq.ft. without an undue increase in steel content, and of ensuring adequate corner strength to resist racking forces. These possibilities could be examined when further test data on the behaviour of reinforced concrete under atomic blast are available.

Effect of softer radiation. The possibility exists that the radiation from an atomic bomb may have a lower energy, and hence a lower penetrating power, than has been assumed for calculating radiation casualties. If future atomic bomb trials should confirm this, then the thickness of concrete required for the optimum shelter designs will be reduced somewhat, and the optimum thickness of concrete may be found not to exceed 12 ins. for any degree of shielding.

Effect of larger bombs. If larger bombs are used, the effect will be to reduce somewhat the thickness of concrete required for the optimum design. For example, the optimum design of moderately shielded shelter against an 8 times nominal bomb is the 12"/1400 lb/sq.ft. compared with the 15"/1400 lb/sq.ft. design required with similar shielding conditions against the nominal bomb.

Trench shelters

Sixteen designs of standard reinforced concrete lined trench shelters 35 ft. long by 7 ft. wide are studied by the methods summarised above for surface shelters. The designs have earth covers of 1, 2, 3, and 5 ft. and strengths of 250, 500, 1000 and 1400 lb/sq.ft. Since trench shelters are likely to be built for the most part in open spaces, the shelters have been assumed to be unshielded.

Within the limits studied the optimum trench shelter is found to be the 1400 lb/sq.ft. design with about 18 ins. of earth cover. It is possible however, that a trench designed to withstand some pressure greater than 1400 lb/sq.ft. and with 2 ft. of earth cover might give a slightly higher safety/cost rating against the nominal bomb.

H.E. attack

All the designs considered above would have about the same safety and safety/cost ratings against the minor danger of H.E. attack as against the major danger of atomic attack, and it is suggested that these shelters should be judged on their atomic ratings.

Results of the study and Conclusions

Particulars of the safety and safety/cost ratings of the optimum shelters are given in the following tables, which also include corresponding particulars for the optimum "well shielded" surface shelter if used in a moderately shielded position, and for Grade A surface and trench shelters. All these shelters are designed to withstand a blast pressure of 1400 lb/sq.ft.

Surface Shelters (Reinforced Concrete)

Shielding	Wall and roof thickness	Safety rating	Cost per seat	Safety/Cost rating
Good	12" (Optimum)	75.5	£15.5	4.87
"	24" (Grade A)	86.5	21.4	4.04
Moderate	12"	65.4	15.5	4.22
"	15" (Optimum)	75.2	16.7	4.50
"	24" (Grade A)	86.0	21.4	4.02
None (open sites)	18" (Optimum)	73.8	18.9	3.90
	24" (Grade A)	82.9	21.4	3.87

Trench Shelters ($7\frac{1}{2}$ in. R.C. roof $5\frac{1}{2}$ in. R.C. walls)

	Earth cover			
None (open sites)	18" (Optimum)	85.0	17.1	4.97
	24" (Grade A)	86.8	17.8	4.88

During the course of this study it became clear that the differences between the thicknesses of the three optimum surface shelters (evaluated for shielding angles of 68°, 34° and 0°) are not so great as to suggest that consideration should be given to more than three grades of shielding. For shelters in streets, a site might be regarded as -

Open, if the shielding angle to the roof of the building on the opposite side of the street is less than 17°;
Moderately shielded, if it is between 17° and 51°; and
Well shielded, if it is more than 51°.

Some allowance might however have to be made for marked variations in the height of the buildings in the street.

Open sites. It will be seen that in an open site the optimum trench shelter (which comes very near to Grade A) gives better protection at less cost than the optimum surface shelter. Trench shelters should therefore be preferred to surface shelters in open sites, wherever practicable.

Well shielded sites. Here the optimum surface shelters have not so high a safety rating as the optimum trench shelter in an open site, but the cost is lower and the safety/cost rating is nearly the same. In well shielded sites it would commonly be difficult to dig a trench, and the exits from a trench shelter would be more liable to serious blockage by debris than those of a surface shelter. In general therefore the optimum surface shelter is recommended for well shielded sites.

Moderately shielded sites. Here trench shelters may occasionally be practicable and, if so, they should be preferred to surface shelters since they have a substantially higher safety and safety/cost rating and the risk of their exits being blocked by debris is less than in well shielded sites. As regards surface shelters, the 15 in. shelter has, at a slightly higher cost, a distinctly better safety rating than the 12 in. shelter, but this would not be so with bigger bombs or softer radiation. For speed of working, there would be considerable advantages in adopting a single design for well or moderately shielded shelters; but, if so, the question would arise of putting the lower limit for moderate shielding higher than 17°. It is proposed to give further consideration to that question in conjunction with studies regarding Anderson shelters and basements in framed buildings.

PART ONE. REINFORCED CONCRETE SURFACE SHELTER

I. Introduction

1. It has sometimes been stated that a basic principle of shelter design against the atomic bomb is that the designs should be balanced; i.e. that they should provide comparable protection against blast and gamma radiation at the same distance. Put in another way it has been said that there is no point in providing protection against blast at a distance where the shelter occupants will, in any case, be killed by gamma radiation, and vice versa.

2. For a particular bomb size and height of burst this principle would be correct if the distance-risk curves for both blast and gamma radiation were of the form shown in diagram 1, i.e. if there was a sharply defined critical distance below which all shelter occupants were killed and beyond which all were safe. In practice, of course, there is no such sharply defined critical distance. Factors of bomb orientation, shielding, vagaries of blast, variations in workmanship from shelter to shelter, and variation in the resistance of people to gamma radiation result in there being a considerable distance band over which some shelter occupants are killed and some survive. The true shape of the distance-risk curve is probably as indicated in diagram 2; this was the shape of the distance-risk curves from high explosive bombs in the last war and for the total casualties from the atomic bombs at Nagasaki and Hiroshima. If the distance-risk curves from blast and from radiation are of this shape it means that, within limits, any increase in safety against either blast or radiation will result in a reduction of casualties even though it leads to an unbalanced design.

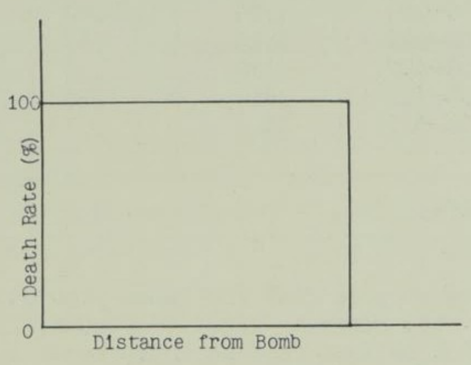

DIAGRAM 1

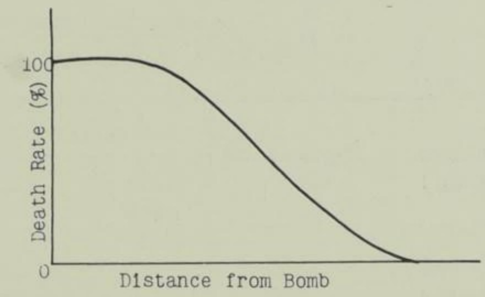

DIAGRAM 2

3. Consider a balanced shelter design in which the distance-risk curves for both blast and radiation are as shown by the full curve in Fig.1. Deaths in this hypothetical shelter for a standard population density (43.6 per acre) are calculated in Table 1, and it will be seen that they total 11,760.

TABLE 1

Deaths in Hypothetical Shelter
(Equal blast and radiation protection)

Annulus (yards)	Population	Blast		Gamma radiation		Combined	
		Death Rate	Deaths	Death Rate	Deaths	Death Rate	Deaths
0-100	280	1.0	280	1.0	280	1.0	280
100-200	850	1.0	850	1.0	850	1.0	850
200-300	1410	1.0	1410	1.0	1410	1.0	1410
300-400	1980	.97	1920	.97	1920	1.0	1980
400-500	2540	.83	2110	.83	2110	.97	2460
500-600	3110	.56	1740	.56	1740	.81	2520
600-700	3680	.26	960	.26	960	.45	1660
700-800	4240	.07	300	.07	300	.14	600
Total			9570		9570		11760

Now suppose that the gamma protection is improved to that represented by the dotted curve in Fig.1. Deaths will now be as calculated in Table 2, and it will be seen that an improvement in gamma protection which has reduced gamma deaths by 35% has reduced total deaths by 13%.

TABLE 2

Deaths in Hypothetical Shelter
(Improved protection against gamma radiation)

Annulus (yards)	Population	Blast		Gamma radiation		Combined	
		Death rate	Deaths	Death rate	Deaths	Death rate	Deaths
0-100	280	1.0	280	1.0	280	1.0	280
100-200	850	1.0	850	1.0	850	1.0	850
200-300	1410	1.0	1410	.96	1350	1.0	1410
300-400	1980	.97	1920	.80	1580	.99	1960
400-500	2540	.83	2110	.52	1320	.92	2340
500-600	3110	.56	1740	.21	650	.65	2020
600-700	3680	.26	960	.05	180	.30	1110
700-800	4240	.07	300	0	0	.07	300
Total			9570		6210		10270

4. This example clearly shows that if improved blast or gamma protection can be obtained relatively cheaply, it may well pay to incorporate it even though it results in an unbalanced design.

II. Type of Surface Shelter

5. For the purpose of this study one type of reinforced concrete surface shelter has been considered, the particulars of which are as follows:-

Internal height 7 ft; internal width 7 ft.
Internal length 35 ft. (including two closets).
Capacity: 50 persons seated (about 4.4 sq.ft./person)
Two baffled entrances, one at each end; each 2 ft. wide.

A sliding joint under the floor.

Ventilation is provided by high level inlet apertures on a scale of $1\frac{1}{2}$ sq.in. of aperture per sq.ft. of occupied floor area (excluding closets), 50% of the apertures being in each side wall, and by an equal area of low level apertures in each side wall. Two closets have separate ventilation apertures at high level.

III. Design of Surface Shelters

6. No satisfactory theory is at present available which will enable shelters (or other structures) to be designed to resist a specified atomic blast pressure. The best that can be done is to use the observations from Hiroshima and Nagasaki, which suggested that reinforced concrete structures would fail under a peak hydrostatic blast pressure of about 7 times their estimated static yield load. On this basis the surface shelters, which are of in situ reinforced concrete with roof and wall thicknesses of 12, 15, 18 and 24 ins. as shown in Fig. 2 have been designed for the following loads, at yield stresses in the steel:-

(a) A vertical superimposed load of 250, 500, 1000 and 1400 lb/sq.ft. respectively, in addition to the dead load, in each case.

(b) A horizontal superimposed load of the same intensity on each side.

7. The above loads have been considered as acting on the roof and all sides simultaneously. The cross section of each shelter has been designed as a two hinged portal frame. The moments of resistance of the roof slab and walls have been calculated from the formula given in paragraph 74 of "Air Raid Shelter".*

8. The minimum amount of main steel in each slab is 0.1% of the gross cross sectional area of the concrete, and is in accordance with the recommendations given in Codes of Practice 114. The cover to reinforcement is also in accordance with C.P. 114. The distribution steel in the roof and walls has been provided at 0.025% of the gross cross sectional area of the concrete. The distribution steel in the floor slab has been provided at 0.05% of the gross cross sectional area of the concrete.

Note: In certain designs the amount of main reinforcement required to resist the design loads is less than the minimum permissible percentage; the minimum permissible percentage is the criterion in the following cases:-

24/250	24/500	24/1000	and 24/1400
18/250	18/500	18/1000	
15/250	15/500		
12/250	12/500		

IV. Height of Burst of Bomb

9. The assumptions made with regard to height of burst have a profound influence on the optimum shelter design. For example with a high air burst (2,000 ft. as at Nagasaki) all the radiation casualties in surface shelters would be due to radiation penetrating the roof, and if this were the only height of burst to be considered it would clearly be efficient to increase the radiation protection of the roof (possibly by means of earth) and to allow the wall thickness to be determined solely by the strength requirements for blast resistance. On the other hand for a ground burst or low air burst most of the radiation strikes through the walls, which might require to be thickened for gamma protection against this height of burst.

10. It is therefore clearly essential that any proposed designs should be studied against all probable heights of burst. In order that the overall

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*Issued by Ministry of Works.

merits of two designs (e.g. one good against a high burst and one good against a low burst) may be compared, it is necessary to assign probabilities to the various heights of burst. These probabilities must, in the nature of things, be quite arbitrary. The method adopted for estimating them was to invite a number of members of the staff of the Scientific Advisers' Branch, Home Office with experience of assessing the effects of a nominal atomic bomb burst at various heights to make independent estimates of the relative probabilities of bursts at heights of $\frac{3}{8}$ mile, $\frac{1}{4}$ mile, $\frac{1}{8}$ mile and ground level.

11. These independent estimates are shown in Table 3.

TABLE 3

Estimates of probabilities of heights of burst

Height of burst (miles)	Estimate (1)	Estimate (2)	Estimate (3)	Estimate (4)	Mean
$\frac{3}{8}$	.12	.15	.20	.20	.17
$\frac{1}{4}$	.38	.30	.30	.30	.32
$\frac{1}{8}$	.38	.45	.40	.30	.38
0	.12	.10	.10	.20	.13

12. Although the four estimates are in rather good agreement too much importance should not be attached to this fact since all four estimators had similar experience of assessments, and had previously discussed the relative merits of different heights of burst with one another on a number of occasions. However it does not seem to be possible to arrive at a better basis, and shelter designs will therefore be studied against bursts at $\frac{3}{8}$ mile, $\frac{1}{4}$ mile, $\frac{1}{8}$ mile and ground level, the relative probabilities of bursts at these heights being taken as 0.15, 0.35, 0.35 and 0.15.

V. Distance-Risk Relationship for Blast

13. It is clear from Section I that the exact shapes of the distance-risk curves for blast and for radiation have a considerable bearing on the overall safety of a shelter. Unfortunately there appears to be no direct way of determining the shape of this curve for blast. The shelters in the present studies have been designed at yield stresses to resist static loads equal to 1/7 of the peak hydrostatic pressure in the blast wave. It is anticipated therefore that the shelters will be seriously damaged, but will not actually collapse, at the corresponding design distances from ground zero. It is not known what percentage deaths this serious damage would cause. It is thought that the killed will probably be less than 50% and a figure of 40% has been arbitrarily assumed.*

14. In order to draw curves showing the percentage deaths at other distances it is assumed that if the pressure is 50% more than the design figure practically everyone (95%) is likely to be killed, and that if the pressure is 25% less practically nobody (say 5%) will be killed.

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* This question has been previously referred to in:-

CD/SPR/20 Appendix 4
CD/SPR/57 Appendix 11
CDJPS(EA)(48)14(Revised) Appendix 2.

15. On this basis, and from blast pressure-distance data for various heights of burst,[*] it is a simple matter to draw distance-risk curves for blast deaths for each of the design pressures and for each of the four assumed heights of burst. The curves for 1400, 1000 and 500 lb/sq.ft. are reproduced as Figs. 3, 4, and 5.

VI. Distance-risk Relationship for Gamma Radiation

(A) Penetration Formula

16. Previous Work. A.R.E. Report H13/51 describes a method for the accurate determination of the dose rate at the centre of a shelter, provided that the radiation arrives as a homogeneous parallel beam of known energy. By means of certain simplifying assumptions the method can be extended to cover the dose at points other than the centre, and this was done in a recent paper by the Scientific Advisers' Branch, Home Office[∅], where the variation in dose across the horizontal mid-plane of a shelter due to a homogeneous parallel beam was studied. The method was laborious and of insufficient accuracy to justify its adoption for a large scale study. However, for want of anything better, certain of its results as given in CD/SA 41 Table 7, have been taken as the standard of comparison for other simpler methods.

17. Slant thickness method based on AERE formula. It is shown in CD/SA 41 paragraph 4 that for radiation of energy 3 MeV the dose in a shelter as calculated by the A.E.R.E. formula

Penetration Factor = $\exp(-S/6.75)$ where S is the thickness of the concrete in inches,

in many cases agreed well with that given by the full A.R.E. method of computation, provided that S was taken as the slant thickness of the face in the line of sight.

18. The shelter was therefore considered as divided into two portions depending on whether the line of sight to the bomb passed through the roof or wall, and the dose in each portion calculated using the appropriate slant thickness. The relative volumes of the two portions were calculated (assuming for comparison with CD/SA 41 results, a shelter 30' x 10' x 10', walls 2 ft. thick). The death rate in each portion was then calculated on the basis of linear variation between 0% killed at 300r and 100% killed at 700r.

19. It is realised that this relationship gives a somewhat lower lethality particularly for doses in the 200-400r. range than that given by the Medical Research Council. However, it is more convenient for purposes of calculation than the M.R.C. figures; it is the relationship adopted for previous atomic casualty studies, and any tendency it may have to underestimate radiation casualties should be compensated for to some extent by the overestimate resulting from the assumption that all the radiation arrives as a homogeneous beam. In fact a proportion of the radiation, the exact amount depending on the distance from the bomb, will be scattered radiation which will have a much reduced penetrating power.

20. From these death rates and relative volumes the average death rate from radiation for the shelter as a whole was calculated and the results are shown in Col. 7 of Table 4.

21. This slant thickness method allows for the scattered and unscattered radiation received from the face in the line of sight but ignores the

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[*] J.H. Bird "The pressure on the ground at large distances from an air burst bomb". Armament Research Establishment Memo No. 10/1950.

[∅] "Gamma Ray Penetration of Grade A. Concrete Shelters. Comparison of Dosage and Casualty Estimates based on A.R.E. Report H13/51 with earlier estimates based on an A.E.R.E. formula" Report No. CD/SA 41.

scattered radiation from the face not in the line of sight, thus producing an artificially sharp demarcation in the doses in the two portions of the shelter. An attempt was made to overcome this by calculating the weighted average dose over the whole shelter and hence the average death rate. The results as shown in Table 4 column 8 did not agree as well with the CD/SA 41 "standard" results (Table 4 column 15) as the previous ones.

22. Some calculations were also done using slant thickness and figures given by Hirschfelder and Adams (*) but the results did not agree as well with the "standard" ones as those given by the A.E.R.E. formula.

23. Modified ARE Method. The shelter was again considered as divided into two portions depending on whether the line of sight was through the roof or wall. The dose at a point very close to the roof or wall could be readily calculated by the ARE method and this was taken as the dose throughout the portion of the shelter receiving its energy through that face. The average death rate from radiation based on the death rate in each portion and the relative volumes thereof, was then calculated as before - see Table 4 column 14.

24. An attempt was made to distinguish between the scattered and unscattered radiation, so as to allow for the fact that the scattered radiation from each face filled the whole of the shelter and not only the portion in the line of sight of the scattering face. To do this satisfactorily allowance had to be made for the variation in the scattered radiation across the shelter and this complicated the method unduly.

25. Method adopted. In view of its simplicity and reasonably good agreement with the so-called "standard" results the slant thickness method, the results of which are given in Col. 7 of Table 4, was adopted for all calculations of the gamma dose inside a shelter.

(B) Shielding by surrounding buildings

26. The amount of shielding by surrounding buildings may well be the most important single factor affecting gamma radiation casualties in surface shelters. For example it is shown subsequently (Tables 5 and 7 of the Appendix) that the deaths among a population of standard density (43.6/acre) all in 12 in. reinforced concrete surface shelters designed to 1,000 lb/sq.ft. and sideways on to a bomb burst at a height of $\frac{1}{8}$ mile are 22,650 if the shelters are in the open and unshielded by surrounding buildings, and only 6,780 if they are all in well shielded positions (shielding equivalent to a 50 ft. high building 20 ft. away or better). In practice all degrees of shielding from zero up to almost complete will be encountered, and since shielding has such a large influence on casualties, it is clear that, in theory, the safety-cost relationship for surface shelters ought to be determined for a very large number of shielding conditions. However the labour involved in such a comprehensive study would be prohibitive, and its results might prove impossible to apply since each amount of shielding might call for a slightly different design of shelter, giving rise to a quite unacceptable multiplicity of designs. The best that can be done appears to be to define a limited number (say three) of degrees of shielding, and to work out the safety-cost relationship of each design of shelter for each of these three degrees of shielding. This procedure does mean, however, that variations in actual shielding within each shielding class will lead to quite large variations in safety. It will be realised from the figures given later, in, for example Table 15 that these variations are so large as to swamp most of the errors likely to arise from other causes, e.g. the use of an approximate gamma penetration formula, and to some extent, therefore they justify the approximations used in other Sections.

(* Phys. Rev. 73, p.863, 1948.

TABLE 4

Shelter deaths from radiation as calculated by various methods

In all cases:-

Height of burst = 220 yards
Energy of radiation = 3 MeV
Shelter dimensions = 30' x 10' x 10' walls 2 ft. thick.

Distance from G.Z. (yd)	Position	Probability dose received through		A.E.R.E. Slant Thickness Method				Hirschfelder & Adams			Modified A.R.E. Method			Full A.R.E Method
				Killed by dose from		Average death rate from gamma radiation	Death rate based on average dose	Killed by dose from		Average death rate from gamma radiation	Killed by dose from		Average death rate from gamma radiation	Average death rate from gamma radiation
		Wall	Roof	Wall (%)	Roof (%)	(%)	(%)	Wall (%)	Roof (%)	(%)	Wall (%)	Roof (%)	(%)	(%)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
600	side-on	.82	.18	30	0	25	12	41	0	34	42	0	34	28+
	end-on	1.37	1.63	"	"	14	0	"	"	19	"	"	19	6
500	side-on	.755	.245	92	0	70	52	100	0	75	100	0	75	97+
	end-on	1.02	1.98	"	"	31	0	"	"	34	"	"	34	29
400	side-on	.725	.275	100	0	72	100	100	0	72	100	0	72	100
	end-on	.91	2.1	"	"	30	10	"	"	30	"	"	30	40

\+ The "standard" results in column 15 are all based on the doses in the horizontal mid-plane of the shelter. In the cases marked + the dose near the roof would have been appreciably less than the dose at the mid-plane, and thus these figures are too high for the death rate in the whole shelter.

27. An examination of a number of typical areas in London suggests that, if all conditions of shielding have to be represented by three cases, the most representative values to use for these three cases are:-

(i) Well shielded. Shelter shielded by building 50 ft. high and 20 ft. away. Shielding angle from floor of shelter to roof of shielding building 68°.

(ii) Moderately shielded. Shelter shielded by building 20 ft. high and 30 ft. away, shielding angle 34°.

(iii) Unshielded.

28. Complete calculations of deaths for each of these three conditions of shielding have been made and the results are presented in later sections of this report. In practice it is considered that each of the three shielding angles studied should be taken as representative of a range:- Thus shelters with an actual shielding angle of more than 51° should be considered as well shielded; those with an angle of 17° to 51° as moderately shielded and those with an angle of less than 17° as unshielded.

29. Variations in the construction of the shielding building introduce yet another variable. However it is considered that this can safely be ignored. It was shown in CDJPS(EA)(48)14(Revised) that the weight of material in an ordinary British house was about the same as that in an open box (no roof or floors) with 11 in. concrete walls, and it was considered in that paper to be a satisfactory approximation to represent the shielding building by such an open box. It will be assumed in this paper that all types of shielding building (not only houses) can be represented in this way and that any shielding building can be represented by an 11 in. concrete wall with a height equal to the height to eaves level of the shielding building. For low heights of burst of the bomb the shelter may be shielded by the back wall of the house as well as by the front wall. It is therefore assumed that, in all cases, there is a second 11 in. wall of the same height as the shielding wall and situated 30 ft. behind it.

30. For ground burst bombs it is assumed that if the shelter is shielded at all (i.e. if the shielding angle is more than 17°) it is completely shielded from gamma radiation.

(C) Effect of Shelter Orientation

31. In considering the orientation (e.g. end-on, side-on or oblique) of the shelter relative to the direction of bomb burst, allowance has to be made for the following factors:-

(i) The effects of gamma radiation and blast have eventually to be combined so as to give a "safety rating" for various shelter designs.

(ii) Our knowledge of shelter strength relative to blast pressures is quite insufficient to enable us to estimate the effect of orientation on blast resistance.

(iii) The gamma radiation penetrating a shelter is, as shown in an earlier study (CD/SA 41) markedly dependent on the orientation of the shelter, being a maximum for sideways-on shelters, diminishing as the azimuth angle increases to reach a minimum at about 45°, and increasing again to another (but smaller) maximum in the end-on position.

32. Now CD/SA 41 showed that the contribution of penetration through the side walls decreased very rapidly for azimuth angles greater than about 45°. It also showed that penetration through the end walls was only important between 45° and 90°. On the basis of this limited evidence it is concluded that each wall of the shelter can therfore be regarded as being uniquely responsible for lateral protection from bombs within a 90° arc (the roof, of course, is responsible for overhead protection through the whole 360° range) and the problem of penetration through the side walls and through the end walls can be considered separately.

33. Penetration through side walls (azimuth angles from -45° to +45°). It is clear that limiting the gamma study to the pure "sideways-on" (azimuth angle 0°) position would have the advantage of simplicity, but a study of the effect on the casualties of variations in azimuth angle was required to determine whether there was any risk of such a simplification invalidating the relative casualty estimates for various shelter designs.

34. To eliminate the effects of the end walls the shelter considered was assumed to be infinitely long, of square cross section (7 ft. x 7 ft) and with 18 inch walls and roof.

35. The total radiation deaths* calculated by annuli as described in the introduction were estimated for positions of the shelter such that the azimuth angles between the short axis and the direction of ground zero were 0°, 10°, 20°, 30°, and 40°. For any particular angle of elevation of the bomb the slant thickness of the side walls increases as the azimuth angle increases, and so the casualties due to the dose penetrating the side walls decreases. The slant thickness of the roof remains constant for a fixed angle of elevation of the bomb, but the fraction of the shelter which receives its radiation through the roof rather than through the side increases slightly as the shelter is rotated, and so the total "roof casualties" increase somewhat.

36. Results were calculated for each of the four standard heights of burst ($\frac{3}{8}$ mile, $\frac{1}{8}$ mile, $\frac{1}{4}$ mile, and ground level) and a weighted mean obtained by the use of the weighting factors given in para. 12. The results are presented in Table 5.

TABLE 5

Effect of orientation on unshielded 18 in. shelter

Shelter orientation	Radiation Deaths		
	Through side wall	Through roof	Total
Sideways-on (azimuth angle 0°)	7,640	2,290	9,930
Average of azimuth angles of 0° 10°, 20°, 30°, 40°	6,050	2,390	8,440
Azimuth angle 40°	3,990	2,580	6,570

37. It will be seen that, for an azimuth angle of 40° deaths are 34% less than in the sideways-on position, but when the results are averaged over the 5 positions considered deaths are only 15% less than in the sideways-on position.

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*Here and elsewhere in this paper, "total deaths" are used as a convenient measure of such factors as effect of orientation, effect of shielding etc. When, as here, they are calculated for a particular set of conditions (e.g. a single azimuth angle) they represent a purely hypothetical case and their value is comparative rather than absolute. For example the 9930 deaths shown in Col. 3 of Table 5 would only occur if a standard population density (43.6 per acre) were all in unshielded 18" surface shelters strong enough to resist blast at all ranges where any occupants survived the radiation and if all the shelters were oriented so as to be exactly sideways on to the burst. If 15, 35, 35 and 15 bombs burst respectively at heights of $\frac{3}{8}$ mile, $\frac{1}{4}$ mile, $\frac{1}{8}$ mile and ground level under these conditions, then it is expected that the average deaths would be 9,930.

38. It is clear from Table 5 that, for unshielded shelters orientation is quite an important factor in casualty estimates. However, surface shelters are likely to be used mainly in built-up areas and would, in general, be appreciably, shielded by neighbouring buildings. For shielded shelters, the effect of orientation is likely to be less important than for unshielded shelters since, as the azimuth angle increases, the increase in the slant thickness of the shelter wall will be offset by a reduction in the shielding angle. The results, calculated on the same basis as those in Table 5, for a number of shielded shelters are summarised in Table 6.

TABLE 6

Effect of orientation on shielded 18 in. shelter

Shelter orientation	Shielding conditions	Radiation Deaths		
		through side wall	through roof	total
Sideways-on (0°)	(20 ft. high building	1740	2290	4030
Azimuth angle 40°	(30 ft. from shelter	1680	2980	4260
Sideways-on (0°)	(20 ft. high building	1470	2270	3740
Azimuth angle 40°	(20 ft. from shelter	580	2580	3160
Sideways-on (0°)	(50 ft. high building	60	1100	1160
Azimuth angle 40°	(20 ft. from shelter	20	1690	1710

39. It will be seen from Table 6 that, for shielded shelters, changes in orientation may either increase or decrease the deaths somewhat. However, this variation with orientation is trivial when compared with changes due to shielding, the errors from which source are bound to be fairly large due to the practical necessity of assuming a limited number of standard shielding conditions. Thus it was decided that over the range of azimuth angles from -45° to +45° the effect of orientation could be ignored, and that within this range estimates of casualties due to gamma radiation could be based solely on shelters sideways-on to the burst.

40. Penetration Through End Walls (azimuth angles from 45° to 135°). It was shown in CD/SA 41 that, for unshielded shelters with side and end walls of the same thickness, shelter occupants were better protected in the end-on than in the side-on position. For the present series of shelter designs, with entrances protected by baffle walls at both ends, the occupants of an unshielded shelter are very much better protected in the end-on than in the side-on position. However the position is complicated by shielding; although a street surface shelter may be well shielded by surrounding buildings against side-on attack, it is likely to be quite unshielded in the end-on position, and therefore for shelters well shielded in the side-on position, the end-on position may be the most dangerous. This is illustrated in Table 7 which compares the radiation deaths in the end-on and side-on position for three different degrees of side-on shielding (as before the figures given are the weighted means for the 4 standard heights of burst)

TABLE 7

Comparison of Radiation Deaths in the End-on and Side-on Positions for 18" Shelter

Shielding condition of sides	Radiation deaths side-on	Radiation Deaths. End-on		
		through wall	through roof	Total
Unshielded	9830)	1700	3170	4870
Shielding angle 34°	4030 }			
Shielding angle 68°	1450)			

41. It will be seen that the radiation deaths in the end-on position are about the same as for the moderately shielded side-on shelter. It will also be seen that the majority of the end-on deaths are through the roof; this means that it is not unreasonable to take the pure end-on position (azimuth angle 90°) as representative of the whole end-on range (azimuth angles from 45° to 135°) since although deaths through the end wall will decrease with any change in azimuth angle from 90°, deaths through the roof will remain approximately constant. It was therefore decided that the pure end-on attack (azimuth angle 90°) could be taken as representative of the whole end-on range.

D. Summary of distance-risk rates for radiation

42. Tables 1, 2, 3 and 4 of the Appendix present similar data on distance-risk rates for gamma radiation to that given in Figs. 3-5 for blast. In this case it is more convenient to present the data in tabular rather than graphical form, since it was calculated in this way and it is in this form that it is required for subsequent combination with the blast risk rates. It will be seen that, for the reasons discussed in the preceding sections, separate figures are given for three different degrees of shielding in the side-on position, and for unshielded shelters in the end-on position.

VII. Deaths from Blast and Radiation Combined

43. It is now necessary to combine the blast and radiation risks for each type of shelter, each position (end-on or side-on), each degree of shielding, and each height of burst by the method discussed in the introduction. The results of this combination are given in Tables 5, 6 and 7 of the Appendix for unshielded, moderately shielded and well shielded shelters repectively. The figures given in these Tables are summarised in Table 8 which brings out very clearly the importance of shielding; deaths in a well-shielded 12" shelter may be less than in an unshielded 18" shelter.

TABLE 8

Summary of Deaths in Surface Shelters

Shielding Conditions	Design blast pressure (lb/sq.ft)	Deaths averaged over height of burst and shelter orientation			
		12" Shelter	15" Shelter	18" Shelter	24" Shelter
Unshielded (Shielding angle less than 17°)	No. blast deaths	14,700	10,600	7,400	3,800
	1,400	14,700	11,200	8,100	5,300
	1,000	14,800	11,600	9,000	-
	500	17,900	16,000	-	-
Moderately Shielded (Shielding angle 17° to 31°)	No. blast deaths	10,300	7,100	4,500	2,400
	1,400	10,700	7,700	5,600	4,300
	1,000	11,000	8,300	6,800	-
	500	14,800	14,000	-	-
Well Shielded (Shielding angle more than 51°)	No. blast deaths	6,500	4,500	3,200	1,600
	1,400	7,600	6,000	5,100	4,200
	1,000	8,400	7,200	6,500	-
	500	14,100	13,800	-	-

VIII. Safety-Cost Relationship

44. A good measure of the value of any shelter is clearly its "cost per life saved". To put the results on this basis it is necessary to subtract the calculated deaths for the various type of shelters given in Table 8 from what the deaths would have been if there had been no shelters. For this the figure of 31,000 given in CDJPS(EA)(48)14(Revised) for a population all in houses will be used. Admittedly this figure relates to only one height of burst ($\frac{1}{8}$ mile) whereas the figures in Table 8 are weighted means for four heights of burst. However the exact value assumed will not seriously affect the results.

45. For convenience in the presentation of the results the "lives saved" will be expressed as a percentage of the deaths among a population all in houses (31,000) and this percentage will be called the SAFETY RATING for the shelter. On this scale a completely bomb proof shelter (lives saved 31,000) has a rating of 100 and a house (lives saved 0) a rating of zero. Table 9 summarizes the "safety ratings" calculated in this way from the deaths given in Table 8.

TABLE 9

Safety Ratings of Surface Shelters

Shielding Conditions	Design Blast Pressure (lb/sq.ft.)	Safety Rating			
		12" shelter	15" shelter	18" shelter	24" shelter
Unshielded (shielding angle less than 17°)	No. blast deaths	52.16	65.8	76.1	87.7
	1400	52.5	63.8	73.8	82.9
	1000	52.2	62.6	71.0	-
	500	42.1	48.4	-	-
Moderately Shielded (Shielding angle 17° to 51°)	No. blast deaths	66.7	77.1	85.5	92.3
	1400	65.4	75.2	81.9	86.0
	1000	64.4	73.3	78.0	-
	500	52.2	54.8	-	-
Well shielded (Shielding angle more than 51°)	No. blast deaths	79.0	85.5	89.6	94.8
	1400	75.5	80.6	83.5	86.5
	1000	72.9	76.8	78.9	-
	500	54.5	55.5	-	-

46. The costs of the various types of shelter are summarised in Table 10 and plotted against the appropriate safety ratings in Fig. 6. These costs are based on Grade A labour rates and prices of materials ruling at February, 1952, for construction on level sites in virgin ground and exclude the cost of any roads, paths and site work generally. The cost of electric wiring is included, but not the cost of bringing in the service mains. The cost of seating and internal fittings is not included.

TABLE 10

Cost per Head of Surface Shelters

Thickness of Concrete	Design Blast Pressure (lb/sq.ft.)	Cost per Head (£)	Weight of steel per head (lb.)
12"	1400	15.5	45.0
	1000	15.2	36.8
	500	14.6	23.1
15"	1400	16.7	44.4
	1000	16.4	31.6
	500	16.0	28.5
18"	1400	18.9	43.4
	1000	18.5	34.8
24"	1400	21.4	48.2

47. It will be noted that, in Tables 8 and 9 figures are given for a design blast pressure sufficient to ensure that deaths occur from gamma only (i.e. that there are no blast deaths). The actual design blast pressure needed to ensure this would vary with the thickness of the shelter and the amount of shielding, but in many cases would be little more than 1400 lb/sq.ft. In all

cases the curves of Fig. 6 for the various thicknesses of concrete have been extended beyond the highest calculated point (1400 lb/sq.ft. pressure) so as to be asymptotic to this "all gamma" case, but it must be pointed out that the actual shape of the curves between the "1400" point and this asymptotic value is largely a guess.

48. From the curves for each concrete thickness plotted in Fig. 6 an envelope curve for each degree of shielding can be drawn indicating the most efficient design, and this has been done in the figure. It is clear that any shelter represented by a point lying below and to the right of these envelope curves is inefficient since its "cost per life saved" is higher than for a shelter lying on the curve. Thus it can be seen (interpolating where necessary and assuming that the "guessed" shapes of the curves above 1400 lb/sq.ft. are correct), that for unshielded shelters the most efficient design for a shelter 12 ins. thick would be one designed for about 800 lb/sq.ft. and for a shelter 15 ins. thick one designed for 100 lb/sq.ft. For the 18" and 24" shelters it appears that efficiency could only be secured by designing them for greater blast pressures than 1400 lb/sq.ft. For moderately shielded shelters the most efficient design for a shelter 12 ins. thick would be one designed for about 900 lb/sq.ft., and for a shelter 15 ins. thick, one designed for about 1400 lb/sq.ft. Thicker shelters should be designed for higher blast pressures than 1400 lb/sq.ft. to be efficient. For the well shielded shelters only the 12"/1400 lb./sq.ft. design is efficient, all the other thicknesses should be designed for a higher blast pressure than 1400 lb/sq.ft. These results could, of course have been obtained directly from Tables 9 and 10 without recourse to the curves. The most efficient shelter in each group is that which has the greatest "safety/cost rating" (i.e. the lowest cost per life saved per bomb) and these will be found to correspond with the designs listed above. An alternative way of presenting these results is shown in Fig. 7 where the safety/cost ratings are plotted against thickness for the various designs and conditions of shielding. These curves illustrate where the various maxima occur rather more clearly than does Fig. 6.

49. One other important conclusion is suggested by the curves of Fig. 6. It is that for each degree of shielding, there is a minimum standard of shelter below which it does not pay (in terms of cost per life saved) to go. This minimum is given by the point at which the tangent from the origin touches the appropriate envelope curve, i.e. the point at which the overall safety rating per £ per person is a maximum; this again is the safety/cost rating and is the true measure of the safety and economy of any particular shelter design. It will be seen from Fig. 6 that the shelters with the highest safety/cost rating are as follows:-

<u>Unshielded</u>	about 18 ins. thick designed for about 1400 lb/sq.ft; safety/cost rating 3.86.
<u>Moderately Shielded</u>	About 15 ins. thick designed for about 1400 lb/sq.ft; safety/cost rating 4.5.
<u>Well Shielded</u>	About 12 ins. thick designed for about 1400 lb/sq.ft; safety/cost rating 4.85.

50. Since the adoption of the shelter with the highest safety/cost rating yields the best return in terms of cost per life saved, and since there seems to be little prospect, in the time likely to be available for building shelters, of building shelters of a higher standard than this, this standard will be referred to subsequently as the "optimum" standard or design.

51. A simple numerical example will illustrate the advantages of adopting this optimum standard. The cost/head of the optimum design for moderately shielded shelters (15"/1400 lb/sq.ft.) is £16.7 and the safety rating 75.2. In other words this shelter would save 75.2% of the casualties in any area where it was used and which was attacked with an atomic bomb. For the same cost (£16.7 per head) 24"/1400 lb/sq.ft. shelters could clearly be provided for $\frac{16.7 \times 100}{21.4} = 78\%$ of the inhabitants leaving the remainder with no shelter at all. The average safety rating of the population under these conditions would be 0.78 x 86.0 = 67.0. The safety rating for this combination is therefore 8.2% lower than for the optimum shelter i.e. casualties would be 8.2%

higher. Alternatively suppose resources are not sufficient to provide the optimum shelter for everyone, and that the sum available is only £14.6 per head. For this everyone could be provided with 12"/500 lb/sq.ft. shelters with a safety rating of 52.2. Or $\frac{14.6 \times 100}{16.7}$ = 87.5% of the population could be provided with optimum shelters (15"/1400 lb/sq.ft.) and leave the rest without shelter. The average safety rating of the population for this case would be .875 x 75.2 = 66.0. Thus here again it has paid in terms of lives saved to use the optimum standard even though it means leaving some people without shelter. The safety ratings given above can of course be converted directly into lives saved per bomb for any area in which the population density is known. Thus for a single bomb on an area of standard density (43.6 per acre) an increase in safety rating from 52.2 to 66.0 means a saving of 13.8% of 31,000 or 4,300 lives.

52. This conclusion, that there is an optimum standard for shelters, is of the utmost importance. It means that if only limited funds are available for building shelters it will pay better (in terms of lives saved) to build a limited number of shelters of the optimum standard, rather than to attempt to provide everyone with shelter of some lower standard. Of course if funds are sufficient to provide everyone with shelter of better than the optimum standard, so much the better, but this seems to be a rather unlikely eventuality.

IX. Possible use of Thinner Roofs Supplemented by Earth

53. So far in this study shelters have been considered with walls and roof of equal thickness. However in designing a shelter, one of the problems is to find the best possible allocation of the available material as between walls and roof. Assuming that the walls and roof have equal mechanical strength (i.e. equal blast resistance), the material should clearly first be concentrated on whichever is letting through the most gamma radiation. Thus against a ground burst the sides and end should be thickened at the expense of the roof, while against a 3/8 mile burst the reverse should be done.

54. Combined blast and radiation deaths have been calculated, and are shown in Table 11 below, for moderately shielded shelters with a static strength of 1400 lb/sq.ft. and 12" walls, with varying roof thicknesses.

TABLE 11

Deaths for different roof thicknesses, 12" walls

Height of Burst	12" roof	15" roof	18" roof	21" roof	24" roof	No gamma deaths through roof
0 miles	10,780	10,780	10,780	10,780	10,780	10,780
$\frac{1}{8}$ mile	9,820	8,900	8,860	8,810	8,810	8,810
$\frac{1}{4}$ mile	13,040	11,090	9,800	9,130	8,770	8,640
$\frac{3}{8}$ mile	7,580	5,030	3,090	1,430	340	60
Weighted Mean	10,750	9,370	8,610	8,110	7,820	7,730

55. Using Tables 11 and 8 and assuming for the present purpose that two shelters with the same volume of concrete will cost the same, the efficiency of thickening the roof only, can be compared with that of thickening the roof and walls uniformly. This has been done in Fig. 8 in which safety ratings are plotted against concrete volume, for various combinations of roof and wall thickness.

56. It will be seen that thickening the roof only is slightly advantageous for small changes and definitely disadvantageous for large ones. The curves suggest that the ideal is to have the roof about 3 or 4 inches thicker than the walls, but the gain is a small one. However this conclusion depends very critically on the weighting of the various heights of burst. If more weight were given to the greater heights, particularly to the $\frac{3}{8}$ mile there

would be a large gain from thickening the roof rather than the walls. Conversely if more weight were given to the ground level burst it would probably pay to have the walls thicker than the roof.

57. Earth is cheaper than concrete, and an alternative to thickening the roof concrete is to pile earth, held in position by a parapet wall, on top of the shelter.

58. The cost of various thicknesses of earth with parapets of sand bags, hollow concrete blocks, brick walls and in situ concrete have been determined and are given in Table 12.

TABLE 12

Costs of Earth or Sand on Roofs of Surface Shelters

Construction of parapet wall to retain earth or sand	Height of wall and fill (in.)	Cost per shelter size 43' x 9' (£)	Cost per inch of fill (£)
Sandbags	5	14	2.8
	10	28	2.8
	15	48	3.2
	20	68	3.4
Hollow concrete blocks 18" x 9" x 9"	9	27	3.0
	18	51	2.8
Dwarf brick wall in mortar	6	18	3.0
	12	35	2.9
	18	60	3.3
Concrete curb	6	32	5.3
	12	61	5.1
	18	91	5.1

59. It will be seen that the cheapest type of parapet depends on the height of fill, but that all heights up to 18" can be provided for a cost of £2.8 per inch of fill. The corresponding cost for each extra inch thickness of concrete on the roof can be deduced from Table 10 to be about £7 per inch or, allowing for the fact that 1½ inches of earth are required to give the same radiation protection as 1 in. of concrete, about 1.7 times the cost of earth fill.

60. Table 13 shows the improvement in the safety-cost relationship that could be achieved by various thicknesses of earth fill on the roof of a 12"/1400 lb/sq.ft. surface shelter.

TABLE 13

Effects of Earth Fill on Roof of 12"/1400 lb/sq.ft. Shelter

Thickness of earth fill (ins.)	Cost/Head (£)	Safety Rating	Safety Rating per £ per head
0	15.5	65.4	4.22
4½	15.75	69.8	4.43
9	16.0	72.2	4.51
13½	16.25	73.8	4.54
18	16.5	74.8	4.53

61. It will be seen that, in this case, it pays to add up to about 13½" of earth fill on top of the shelter.

62. Calculations similar to the above have not been made for other shelter designs; in particular they have not been made for the optimum design of moderately shielded shelter (15"/1400 lb/sq.ft.) However it seems fairly clear that where the basic concrete design is thicker it will pay to add rather less earth - probably about 10 ins. for a 15" shelter.

63. Since earth is cheaper than concrete, and since all the present series of designs are somewhat under-reinforced (the reinforcement in the roof of the 12"/1400 lb/sq.ft. design is only 0.25%) it is clear that the possibility exists of producing a more efficient design by reducing the thickness of the roof concrete to perhaps as little as 6 to 8 ins. and making up the balance of the required roof thickness with earth. However the true relative contributions to blast resistance of the steel and the concrete in a reinforced concrete slab are at present uncertain, and with a thinner roof there might be some difficulty in ensuring adequate corner strength to resist racking forces. For the present, therefore, designs should probably be based on equal roof and wall thicknesses, but the possibility of reducing the roof thickness should be re-examined when further test data on the behaviour of reinforced concrete under atomic blast are available.

X. The effect of less penetrating radiation

64. The penetration formula used hitherto in this paper for the calculation of distance-risk rates for gamma radiation corresponds to an energy of about 3 MeV. There is, however, some evidence that the incident radiation may have a lower penetrating power, corresponding to an energy of less than 3 MeV. Some of the calculations have therefore been repeated using, for convenience, penetration factors given by Hirschfelder and Adams for radiation of energy 1 MeV. These are considerably lower than for 3 MeV radiation; for instance, for 12 inches of concrete the penetration factor is reduced to about a quarter of its former value if the energy is reduced from 3 to 1 MeV, and for 24 inches of concrete it is reduced to one-tenth of its previous value.

65. The distance-risk rates for a 12" shelter both unshielded and with medium shielding are shown in Table 8 of the Appendix for radiation of energy 1 MeV, and the deaths resulting from combining the blast and radiation risks in Table 9 of the Appendix. The latter figures are summarised in Table 14 which also shows for comparison the figures taken from Table 8 for 3 MeV radiation and the deaths which would result if the shelter were subjected to blast alone. Figures for shelters thicker than 12 ins. have not been calculated for 1 MeV radiation since even with the 12 in. shelters the majority of the deaths are due to blast and the potential gain from thicker shelters is very small.

TABLE 14

Comparison of deaths in 12" surface shelters for 3 MeV and 1 MeV radiation

Shielding conditions	Design Blast pressure	Deaths in 12 in. shelter averaged over height of burst and shelter orientation	
		Assuming 3 MeV radiation	Assuming 1 Mev radiation
Unshielded	No. blast deaths	14,700	5,000
	1,400	14,700	6,300
	1,000	14,800	7,500
	500	17,900	14,000
Moderately shielded	No. blast deaths	10,300	2,900
	1,400	10,700	4,600
	1,000	11,000	6,200
	500	14,800	13,500
So well shielded that deaths are due to blast only	No. blast deaths	-	-
	1,400	4,000	4,000
	1,000	5,700	5,700
	500	13,400	13,400

Table 14 shows clearly the enormous influence on deaths of the assumption made as to energy of radiation particularly in strong, unshielded shelters. For example the 14,700 deaths in unshielded 1400 lb/sq.ft. shelter calculated for 3 MeV radiation are reduced to only 6,300 if the radiation is of 1 MeV energy.

66. Fortunately, however, the assumed energy of the radiation does not greatly affect the choice of design. This is shown in Table 15 which compares the safety/cost rating of the various thicknesses of shelters against 3 MeV radiation with those of the 12 in. shelter against 1 MeV radiation.

TABLE 15

Efficiencies of surface shelters against 3 MeV and 1 MeV radiation

Shielding	Design Blast pressure (lb/sq.ft.)	Safety/cost rating of shelter				
		1 MeV Radiation	3 MeV radiation			
		12" Shelter	12"	15"	18"	24"
Unshielded	1400	5.14	3.39	3.82	3.91	3.87
	1000	4.99	3.44	3.83	3.84	
	500	3.75	2.88	3.11	-	-
Moderately Shielded	1400	5.50	4.22	4.50	4.33	4.02
	1000	5.26	4.23	4.47	4.21	-
	500	3.86	3.58	3.52	-	-

67. It will be seen that, for the softer radiation the design with the highest safety/cost rating for shelters 12ins. thick is one for at least 1400 lb/sq.ft. for both unshielded and moderately shielded conditions. For the 3 MeV radiation considered earlier the corresponding figures were 800 lb/sq.ft. for unshielded and 900 lb/sq.ft. for moderately shielded 12 in. shelters.

XI. The Effect of Bigger Bombs

68. All the results which have so far been given in this paper refer to a nominal bomb. However it is uncertain what size or sizes of bombs the enemy will use against us and since the relative importance of blast and radiation is dependent on the size of the bomb, it is essential to see how our conclusions would be affected by variations in bomb size. Although bombs smaller than nominal may be used against tactical targets, they would not appear to be very efficient for use against cities and only bombs larger than nominal will therefore be considered. It is impossible to specify any ultimate upper limit of size for atomic bombs, but by studying the effects of an 8N bomb a measure should be obtained of the influence of bomb size on results.

69. The deaths in moderately shielded surface shelters have therefore been calculated for an 8N bomb by the methods used earlier and are given in Table 16 for four heights of burst of $\frac{3}{4}$, $\frac{1}{2}$, $\frac{1}{4}$ and 0 miles. These four heights of burst correspond to the four standard heights given in para. 10 increased by the scale factor of 3 W

TABLE 16

Deaths in Moderately Shielded Surface Shelters from 8N bomb

Height of burst (miles)	1,000 lb/sq.ft.			1400 lb/sq.ft.			No. blast deaths		
	12"	15"	18"	12"	15"	18"	12"	15"	18"
$\frac{3}{4}$	9,200	5,600	3,200	8,800	4,000	800	8,800	4,000	800
$\frac{1}{2}$	29,600	26,000	25,600	26,800	19,600	17,600	26,000	16,000	12,000
$\frac{1}{4}$	29,600	28,400	27,600	26,800	23,600	22,400	24,800	20,400	16,400
0	32,400	30,000	29,600	28,400	24,800	23,600	18,000	13,600	10,800
Weighted Mean	27,200	24,400	23,600	24,400	19,600	17,600	21,600	15,600	11,600

70. Comparing these figures with the corresponding ones of Table 6 of the Appendix for the nominal bomb it will be seen that in all cases the deaths from the 8N bomb are less than 4 times those for the nominal bomb. Although blast deaths increase as the two-thirds power of the bomb size (i.e. a factor of 4 for the 8N bomb), radiation deaths increase more slowly with increasing bomb size, and therefore total deaths are less than four times those for the nominal bomb.

71. In order to convert these deaths into safety ratings we should strictly speaking calculate the deaths in houses for an 8N bomb. However since 30,000 of the 31,000 deaths in houses from the nominal bomb are due to blast we cannot be much in error if we take the figure for the 8N bomb as 124,000 since it must lie between the limits of 120,000 and 124,000. The safety ratings for the moderately shielded surface shelter have therefore been calculated on this basis and are given in Table 17.

TABLE 17

Safety ratings for moderately shielded surface shelters for 8N bomb

Design blast pressure (lb/sq.ft.)	Safety Rating		
	12" shelter	15" shelter	18" shelter
No blast deaths	82.4	87.5	90.6
1400	80.4	84.3	85.8
1000	78.2	80.3	81.0

72. These safety ratings are plotted against cost (from Table 10) in Fig. 9 which also shows the envelope curve for the nominal bomb (From Fig. 6). An examination of Fig. 9 draws attention to the following points:-

(i) The safety ratings of all the shelters are considerably higher against the 8N than against the nominal bomb.

(ii) The 12"/1400 lb/sq.ft. shelter is the optimum design against the 8N bomb (i.e. the design for which the tangent from the origin touches the envelope curve).

(iii) The 15" and 18" shelter should be designed for a higher blast pressure than 1400 lb/sq.ft.

XII. Conclusions

73. In heavily built up areas surface shelters are often the main alternative to basement shelters, trench shelters being ruled out for lack of space. In such areas the surface shelters are likely to be well or moderately shielded. In less heavily built up areas, where surface shelters would be unshielded, it should normally be possible to replace them by trench shelters, which are shown subsequently (Part II) to be considerably more efficient.

74. The most important shielding conditions for surface shelters are therefore the well and moderately shielded cases, and surface shelters should not be built in unshielded positions if trench shelters can be constructed.

75. Shelters in Well Shielded Positions. It is shown in Section VIII that for the nominal bomb and 3 MeV radiation the 12"/1400 lb/sq.ft. is the optimum design for well shielded shelters. For larger bombs or for softer radiation it seems probable that a shelter of less thickness than 12 ins. and greater strength than 1400 lb/sq.ft. would be more efficient. However considerations of protection from H.E. fragments and psychological considerations (the minimum standard in the last war was 12 ins. and the public would consider that if this was required against H.E. something at least as thick was required against atomic bombs) probably rule thinner shelters out of consideration.

76. However even for the nominal bomb and 3 MeV radiation Fig. 6 suggests that it might pay to design the 12 ins. shelter for a rather greater load than 1400 lb/sq.ft. With the prospect of larger bombs and/or softer radiation the efficiency of higher strength designs should perhaps be explored.

77. Shelters in Moderately Shielded Positions. It is shown in Section VIII and Fig. 6 that for the nominal bomb and 3 MeV radiation the 15"/1400 lb/sq.ft. is the optimum design for moderately shielded shelters. However Section XI shows that for an 8N bomb the 12"/1400 lb/sq.ft. is the optimum design and Section X gives practically the same result for 1 MeV radiation. Moreover the advantages of using the same design for both well and moderately shielded positions are obvious. It is therefore recommended for present planning that the 12"/1400 lb/sq.ft. design should also be adopted for moderately shielded positions. If future tests confirm that the energy of the radiation is as high as 3MeV then this choice should be re-examined.

78. Shelters in Unshielded Positions. Calculations for larger bombs and softer radiation have not been made for unshielded shelters, since, as stated above, trenches should, wherever possible, be constructed in preference to surface shelters in unshielded positions. Where this is impossible the optimum design for the nominal bomb and 3 MeV radiation - the 18"/1400 lb/sq.ft. design - should be used. Although it can be argued that the possibility of larger bombs and softer radiation might justify the adoption of a thinner shelter it is considered that the adoption of the more expensive shelter is justified since in doubtful cases it may help to influence local authorities and others to use trench shelters which give much better protection for about the same cost.

79. Possible use of thinner roofs supplemented by earth. Earth is cheaper than concrete and it is shown in Section IX that in the case of the nominal bomb and 3 MeV radiation, the safety/cost rating of the 12"/1400 lb/sq.ft. design for moderately shielded shelters could be improved somewhat by the addition of about 1 ft. of earth. A further possibility, which was not studied in detail in Section IX would be to reduce the roof thickness to 6 or 8 ins. of concrete with the balance of the required thickness provided by earth. This might well provide rather greater safety at rather lower cost then the standard 12"/1400 lb/sq.ft. design recommended above for well and moderately shielded shelter. However the improvement could not be large and would be dependent on the possibilities of designing a thinner slab to carry 1400 lb/sq.ft. without an undue increase in steel content and of ensuring adequate corner strength to resist racking forces. These possibilities should therefore be examined when future data are available on the behaviour of reinforced concrete under atomic blast.

PART TWO

REINFORCED CONCRETE TRENCH SHELTER

I. Type of Trench Shelter

80. For the purpose of this study one type of in-situ reinforced concrete lined trench shelter has been considered, the particulars of which are as follows:-

Internal height 7 ft; internal width 7 ft.
Internal length 35 ft. (including two closets)
Capacity: 50 persons seated.
Stepped entrance at one end; vent shaft and emergency exit at far end.
The shelters are sunk sufficiently for the volume of excavated earth to supply the required volume of earth cover.
The high level ventilation outlet is provided on a scale of 2½ sq.in. of aperture per sq.ft. of occupied floor area (excluding closets). The two closets are close to the ventilation outlet.

II. Design of Trench Shelters

81. The trench shelters are of in-situ reinforced concrete and have been designed in the first instance at normal stresses for peace-time loading. The peace-time superimposed load has been taken at 50 lb/sq.ft.

82. The roof slab and walls were then examined and additional steel provided where necessary to ensure that at yield stresses in the steel the moment of resistance at any point should not be less than the bending moment due to a superimposed load on the ground equal to 250, 500, 1000 and 1400 lb/sq.ft. respectively, in addition to the dead loads, in each case. The bending moment at each point has been taken as being equal to the free bending moment at that point reduced by the value of the restraint moment provided by the steel at yield stress at the corners of the shelter. The moment of resistance has been calculated from the formula given in paragraph 74 of "Air Raid Shelter". The loads due to the superimposed blast pressures have not been distributed across the floor slab. The minimum amount of main steel and cover to reinforcement comply with the recommendations of C.P.114.

83. The maximum amount of main steel is in accordance with the recommendations given in paragraph 74 of "Air Raid Shelter".

84. Distribution steel has been provided at 0.05% of the gross cross sectional area of the concrete.

85. Details of the various designs are given in Fig. 11

III. Outline of Method of Calculating Safety

86. The general method for determining the safety-cost relationship for trench shelters is the same as that described in Part One for surface shelters and is based on the same assumptions regarding distance-risk rates for blast deaths (with the addition of a 250 lb/sq.ft. blast pressure design - Fig. 10), penetration and lethality of the gamma radiation, and the likelihood of heights of burst of 0, $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{3}{8}$ miles. However, since trench shelters would most usually be sited in relatively open spaces such as parks and city squares, it is not necessary to consider the effect of various degrees of shielding and it is assumed in this study that all trench shelters are unshielded.

87. The main difference in the method of calculating safety ratings for surface and trench shelters is that for the former the mean of the number of lives saved with shelters in the end-on and sideways-on position is used, whereas for trench shelters it is sufficient to consider only the end-on position. The reason for this is explained in the following section.

IV. Gamma penetration of end-on shelters

88. The excavation necessary to give trenches 3 ft. or more of earth cover means that they are completely sunk, whereas those with 1 or 2 ft. of earth cover are only partially sunk. No matter which design of trench is considered, it can be shown that radiation meeting the end or side of the trench will, in general, have passed through a much greater thickness of earth than that meeting the roof. This suggests that it may be possible to neglect, at any rate for the initial calculations, the radiation entering the trench through the side or end, and to consider only that entering through the roof of an infinitely long trench in the end-on position. It is clear that for the completely sunk trenches these assumptions of infinite length and end-on position represent the worst case, since for any other position or length of the trench only a portion of it would be filled by radiation passing through the roof, the remainder being occupied by radiation of much lower intensity which has passed through the side or end. This "worst case" condition probably also holds for the trench shelter with only 1 or 2 ft. of earth cover, but the shape of the earth banking over the portion of the side walls above the normal ground level is such that it is necessary also to investigate the side-on position to make sure that this is so.

89. The distance-risk rates for gamma radiation penetrating the roof of an end-on infinitely long trench are given in Table 10 of the Appendix. These rates are based on the assumption that the fraction of the radiation penetrating soil of depth (d) is the same as that penetrating a concrete slab of thickness two thirds (d). The results of combining the radiation and blast risks are given in Table 11 of the Appendix, and these figures are summarised in Table 18 below.

TABLE 18

Summary of Deaths in Trench Shelters
(shelters end-on; infinite length; unshielded)

Earth Cover (ft.)	Roof (concrete) thickness (ins.)	Blast strength (lb/sq.ft.)	Deaths averaged over all heights of burst	
			Combined Blast and gamma	Blast only
1	7.5 (assumed)	No blast deaths	4,900	0
	7.5	1400	6,000	4,000
	6	1000	7,500	5,700
	5	500	13,600	13,400
	5	250	30,500	30,500
2	7.5 (assumed)	No blast deaths	1,900	0
	7.5	1400	4,100	4,000
	6	1000	5,900	5,700
	5	500	13,400	13,400
3	7.5 (assumed)	No blast deaths	550	0
	7.5	1400	4,000	4,000
	6	1000	5,700	5,700
	6	500	13,400	13,400
5	7.5 (assumed)	No blast deaths	0	0
	7.5	1400	4,000	4,000
	6.5	1000	5,700	5,700

90. This Table shows clearly that except for trenches with only 1 foot of earth cover and of 1,400 or 1,000 lb/sq.ft. design blast pressure the deaths are all or nearly all attributable to blast rather than gamma radiation.

91. Thus on comparing the figures of Table 18 for total deaths with those for surface shelters (Part One Table 8) it is not surprising to find that they are much lower even than those for well shielded surface shelters, since in the latter there would always be some radiation deaths.

92. There is no need to consider any position other than end-on for shelters with 3 or 5 feet of earth cover since any diminution in the gamma radiation penetrating the shelter would not alter the number of deaths which even in the end-on or "worst gamma case" position depends only on the design blast pressure. For these shelters the deaths are in fact independent of the orientation and also of the shelter length.

V. Gamma penetration of side-on shelters

93. As stated previously it is necessary to study the sideways-on position for the trenches with only 1 or 2 feet of earth cover since for low heights of burst there may be certain positions of the bomb relative to the shelter such that the equivalent concrete slant thickness of the upper portion of the wall and its covering soil is less than the slant thickness through the roof and its covering soil. In the case of a ground burst bomb it can be assumed that radiation can only enter through the portion of the shelter wall above ground level, and that for the whole of this portion the earth covering has only the minimum thickness as measured horizontally from the top of the shelter. The total combined blast and radiation casualties are shown in Table 19, for a shelter with 1 foot of earth cover.

TABLE 19

Casualties due to a ground burst bomb; trench shelters in the sideways-on position

Earth Cover (ft.)	Wall (concrete) thickness (in.)	Design Blast Pressure (lb/sq.ft.)	Deaths	
			Combined blast and gamma	Blast only
1	5	1400	5,440	5,190
	5	1000	7,000	6,950
	5	500	11,270	11,270
	5	250	23,100	23,100

94. Thus even when the calculations are based on the minimum thickness of earth cover there is little difference, and that only at the higher design blast pressures, between the number of deaths due to both blast and gamma radiation and that due to blast alone. Hence if an average value for the thickness of the earth cover were used any difference between these figures would be negligible. For any position of the shelter other than end or side-on the slant thickness of the wall and earth cover would be greater, radiation effects would be reduced, and the number of deaths would still be the same as that due to blast alone.

95. Considering bombs burst above the ground more careful allowance must be made for the variation in slant thickness of the wall and its earth covering. For a trench with 1 foot of earth cover the portion of the wall (2 ft.) above the ground is considered in two parts and the slant thickness and hence the dose penetrating at points 6 and 18 inches above the ground level determined. Allowing as usual for the fraction of the shelter occupied by these doses, the risk rate due to the gamma radiation through the roof and side is calculated for the shelter as a whole, blast and gamma risks being combined to give the results shown in Table 20. The dose penetrating the wall at a point 6 inches below the ground level can also be determined but it is found that the gamma radiation only has any lethal risk at distances such that the blast risk rate at these distances is unity, and so the radiation has no effect on the total casualties.

TABLE 20

Comparison of deaths in side-on and end-on trenches due to a low air burst bomb

Earth Cover (ft.)	Height of burst (yd.)	Blast Strength (lb/sq.ft.)	Total Deaths		
			Combined blast and gamma		Blast only
			Side-on	End-on	
1	220	1400	5680	5280	5130
		1000	7090	6940	6760

96. For the 500 and 250 lb/sq.ft. design blast pressures the deaths are independent of the shelter orientation and equal to the deaths due to blast alone.

97. These results show that for a 220 yd. height of burst the end-on position does not necessarily give the maximum number of deaths. However, the increase for the side-on position is small and is more than offset by the diminution in deaths for a 440 or 660 yard height of burst when the weighted mean deaths are obtained by averaging over all heights of burst.

98. It can easily be deduced from the detailed calculations for 1 foot of earth cover that with 2 feet of earth cover the sideways-on position will give no increase in deaths over the end-on position for either a ground or low air burst bomb.

99. Thus for these partially sunk trenches the end-on position is the "worst-case" position for shelters of 1400 or 1000 lb/sq.ft. design blast pressure. For the weaker shelters the total weighted mean deaths are the same as for blast alone and so are independent of the orientation of the shelter.

VI. Safety-cost relationship

100. Using the figures for deaths given in Table 18, safety ratings, i.e. lives saved expressed as a percentage of the deaths (31,000) for a population all in houses, can be calculated for the various trench shelter designs, and are given in Table 21.

TABLE 21

Safety ratings for trench shelters

Design blast pressure (lb/sq.ft.)	Safety ratings for earth cover of:-			
	1 ft.	2 ft.	3 ft.	5 ft.
No blast deaths	84.1	93.9	98.3	99.9
1400	80.7	86.8	87.4	87.4
1000	75.8	81.0	81.6	81.6
500	56.1	56.8	56.8	-
250	1.6	-	-	-

101. The costs of the various trench shelters summarised in Table 22 are based on Grade A labour rates and prices of materials ruling at February, 1952 for construction on level sites in virgin ground and exclude the cost of any roads, paths and site works generally. The cost of electric wiring is included, but not the cost of bringing in the service mains. The cost of seating and internal fittings is not included. The costs are based on the assumption that open cut methods of excavation are not practicable; they would be increased where sites are restricted, where old foundations, rock, running sand, are encountered where sewers, gas, electric or water services have to be diverted, or where underpinning of adjacent buildings is necessary.

TABLE 22
Cost of Trench Shelters

Earth Cover (ft.)	Design blast pressure	Cost per head (£)	Weight of Steel per head (lb.)
1	1400	16.4	42.2
	1000	16.1	37.9
	500	15.8	34.0
	250	15.3	32.1
2	1400	17.8	47.3
	1000	17.4	47.0
	500	17.2	44.7
3	1400	19.1	51.9
	1000	18.9	50.5
	500	18.8	48.3
5	1400	22.2	62.3
	1000	22.0	60.5

102. These costs are plotted against the Safety Ratings in Fig. 12.

103. As in the corresponding section for surface shelters, safety ratings for each depth of earth cover are shown in Table 21 for the hypothetical case in which all the deaths are due to gamma radiation only (i.e. no blast deaths) and the safety rating-cost curves of Fig. 12 are extended - largely by guess - beyond the highest calculated point (1400 lb/sq.ft. pressure) so as to be asymptotic to this "all gamma" case.

104. In Fig. 12 the envelope curve shows that for 1 foot of earth cover the most efficient trench would be one designed for at least 1400 lb/sq.ft. but that for greater depths of earth cover the trenches should be designed to withstand greater blast pressures.

105. As explained in the Surface Shelter section (Part One, Section VIII) the point at which the tangent from the origin touches the envelope gives the optimum design of shelter below which it does not pay (in terms of cost per life saved) to go. For these trench shelters this optimum is between 1 and 2 ft. of earth cover and designed for at least 1400 lb/sq.ft.

VII. Effect of Softer Radiation

106. As shown in Table 18 nearly all the deaths in trench shelters are due to blast and it is only in the case of the mechanically stronger designs of trenches with 1 ft. of earth cover that there is any appreciable number of gamma deaths. Thus even if the radiation is less penetrating the only effect will be to increase somewhat the safety ratings for the trenches of 1400 and 1000 lb/sq.ft. blast pressure design and 1 foot of earth cover.

VIII. Conclusions

107. On the basis of the assumptions made in the preceding paragraphs the optimum trench shelter of those studied in this paper is the 1400 lb/sq.ft. design with about 18 ins. of earth cover. The 1400 lb/sq.ft. design has a concrete roof $7\frac{1}{2}$ ins. thick, so that the total cover for the optimum design is equivalent to about $19\frac{1}{2}$ ins. of concrete.

108. Should future tests show the radiation to be less penetrating than assumed, or should bombs larger than nominal be expected then the conclusion that it does not pay to use more than about 18 ins. of earth cover would be strengthened.

PART THREE

COMBINED ATOMIC AND H.E. SAFETY RATINGS

I. Introduction

109. In Parts One and Two of this study we have been concerned solely with safety against atomic attack. This was justified because all the shelters so far studied provided much the same safety against H.E. attack and such small variations as might exist would have little or no effect on the total safety of the shelters measured against a combined threat of which H.E. represented only a small part. Certain types of shelters (e.g. tunnels) with fairly thin overhead cover provide very much better protection against one form of attack than against the other and for these it is considered desirable to devise a combined H.E. and atomic safety rating which will allow better than standard protection from one form of attack to be offset against poor protection from the other.

110. The correct combination of the H.E. and atomic safety ratings demands a knowledge of the relative risks from these two forms of attack. Clearly this cannot be absolutely determined, but it has been stated (C.D.(O)(53)29) that the atomic bomb constitutes the most serious threat and that defence against it should be given the main consideration. This planning assumption will be arbitrarily interpreted to mean that the atomic risk at any rate in the opening phase of a war is 10 times the H.E. risk, i.e. the atomic attack is likely to cause at least 10 times as many casualties among a population in houses as the H.E. attack.

111. Total casualties from the attack may therefore be expressed as 10K atomic casualties and 1K H.E. casualties where K is a constant depending on the total weight of attack. Now if the atomic safety rating of a particular shelter is A, it is clear that it would save $\frac{10AK}{100}$ atomic casualties, and if its H.E. rating is H it would save $\frac{1HK}{100}$ H.E. casualties. The total saving is therefore $\frac{10AK + 1HK}{100}$

Converting this to a safety rating by dividing it by the casualties if there had been no shelter and multiplying by 100 we get:- combined safety rating: $\frac{10A + H}{11}$.

II. H.E. Safety Ratings

112. Appendix A of Ministry of Works Technical Memoranda "Air Raid Shelter" gives a formula from which the "area of vulnerability" of a person in any type of shelter may be calculated for H.E. Attack. This formula is

$$V = \frac{2000}{W} (0.8A + 1.6\, d\, A^{\frac{1}{2}} + 1.26\, d^2)$$

Where V is the area of vulnerability in sq.ft.
W is the weight in lb. of the H.E. bomb under consideration
A is the area of the shelter in sq.ft.
d is the near miss distance (in feet) within which shelter occupants are liable to be killed or injured.

For 500 lb. M.C. bombs d has the values of 12, 7 and 4 for 12 in., 18 in., and 24 in., R.C. walls respectively.

113. Applying this formula to the surface shelters considered in Part 1 gives values for the areas of vulnerability of 3,200 2,120 and 1,610 sq.ft. for the 12", 18" and 24" wall designs respectively.

114. Now last war experience* showed that the area of vulnerability of people in houses was about 5 times that of people in reinforced brick surface shelters. The latter should be equivalent to our present design of 12" R.C. surface shelter (V = 3,200 sq.ft.) and therefore on this basis the area of vulnerability of people in houses should be 16,000 sq.ft. This is in satisfactory agreement with the figure of 13,600 sq.ft. for killed plus seriously injured given in CDJPS(EA)(49)3. The area of vulnerability is, of course, directly proportional to the expected casualties from unit weight of attack, and the safety rating of the 12" R.C. shelter is therefore $\frac{16,000 - 3,200}{16,000} \times 100 = 80$. Corresponding figures for the 18" and 24" shelters are 87 and 90.

III. Combined Ratings for Surface Shelters

115. Table 23 gives the atomic safety ratings for surface shelters (from Table 9 Part One), the H.E. safety ratings, and the calculated combined safety rating (equals $\frac{10A + H}{11}$). For this Table it has been assumed that the H.E. ratings for the appropriate concrete thickness as calculated in para. 114 apply irrespective of the design strength of the shelter. In theory this cannot be true since an increase in strength must be accompanied by an increase in H.E. safety rating. However this increase is not likely to be large and last war data are insufficient to make any quantitative allowance for it.

TABLE 23

Combined Atomic and H.E. Safety Ratings for Surface Shelters

Shielding Conditions	Design blast pressure (lb/sq.ft.)	Safety Rating								
		12" Shelter			18" Shelter			24" Shelter		
		Atomic	H.E.	Combined	Atomic	H.E.	Combined	Atomic	H.E.	Combined
Unshielded	1400	52.5	80	55.0	73.8	87	75.0	82.9	90	83.5
	1000	52.2	80	54.8	71.0	87	72.6	-	-	-
	500	42.1	80	45.7	-	-	-	-	-	-
Moderately Shielded	1400	65.4	80	66.7	81.9	87	82.3	86.0	90	86.4
	1000	64.4	80	65.8	78.0	87	78.9	-	-	-
	500	52.2	80	54.8	-	-	-	-	-	-
Well Shielded	1400	75.5	80	76.0	83.5	87	83.7	86.5	90	86.7
	1000	72.9	80	73.5	78.9	87	79.6	-	-	-
	500	54.5	80	56.9	-	-	-	-	-	-

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*For example "Casualties from H.E. Bombs" CDJPS(EA)(49)3.

116. It will be seen from Table 23 that in no case is the combined rating very different from the atomic rating, and an examination of Fig. 6 shows that none of the conclusions drawn from that figure would be affected if it were drawn (as if should be) in terms of combined ratings instead of only atomic ratings.

PART FOUR

(This part of the paper has been prepared in the Scientific Advisers' Branch Home Office and has not been considered by Ministry of Works.)

EFFECTS OF VARIATIONS IN RISK OF ATTACK

117. The conclusions so far reached about optimum shelter standards strictly speaking only relate to an area or areas where the likelihood of attack is uniform. Where this is not the case then the safety ratings must be multiplied by the relative likelihood of attack to make them proportional to the lives saved, since it is the lives saved which are the true measure of the "safety" of any scheme. For example consider two areas of equal size and equal population density (43.6 per acre) one of which is expected to receive two bombs and the other a single bomb. Suppose that moderately shielded 15"/1400 lb/sq.ft. shelters were built in each (safety rating 75.2). Then in the single bomb area we should save .752 x 31,000 = 23,200 lives and in the two bomb area 2 x .752 x 31,000 = 46,400 lives (assuming that the areas were big enough to absorb the effects of the bombs without overlap). But the total cost of shelters in the two areas would be the same (since their populations are the same) and therefore the cost per life saved in the two bomb area would be half that in the one bomb area. Applying this argument to the safety rating - cost curves of Fig. 6 leads to the following conclusions:-

(i) The "optimum" standards are not affected - it never pays to build shelters to a lower standard than this irrespective of the likelihood of attack.

(ii) If one area is appreciably more likely to be attacked than another, then shelter in the more risky area, should be built to a higher standard than the "optimum" even if this means leaving some of the people in the less risky area without shelter. For example it can be deduced from Fig. 6 that for moderately shielded surface shelters in areas where the risk rates are in the ratio of 2 to 1, everyone in the higher risk area should be given a shelter costing about £19 per head (safety rating 83) before anyone in the lower risk area is given an 'optimum' shelter (cost £16.7, safety rating 75.2)

118. In addition to the variations in risk from area to area discussed above, there will also be variations in risk within a single area which may invalidate the conclusions so far reached regarding the optimum shelter. It cannot be too strongly emphasised that these conclusions are only valid for an area or areas where the risk is uniform. If, in any particular area, a bomb is more likely to fall in one place, than in another, then the provision of optimum shelters throughout the area will not result in the greatest saving in life for the money spent. This point can perhaps be illustrated by considering the case of a fairly small, compact town (population of the order of 50-100 thousand). In such a town the aiming point is fairly certain to be at, or very close to, the centre and therefore irrespective of the accuracy of attack actually achieved by the enemy, the risk at the centre of the town must always be greater than in the suburbs. The numerical variation in risk, and hence in the standard of protection which should be provided, from place to place in the town depends, of course, on the enemy's aiming accuracy. In the limit, however, if it were known that he could burst his bomb at ground level exactly on the centre of the town, then the minimum efficient (or optimum) shelter at each distance from the centre of the town would be that which gave protection at that distance, i.e. we should have to provide "bomb proof" shelter at the centre and no shelter at all beyond about a mile from the centre since people in houses should be fairly safe at that distance. This, of course, is a reductio ad absurdum argument, since aiming points will seldom be precisely determinable, and since attacks will never achieve pin-point accuracy. In practice it might be possible, using some such method as that recommended by

the U.S. authorities[*] to define likely aiming points and to assign a probable aiming error to the attack. In this way the relative risk in different zones in a single area could be estimated, and hence the optimum standard of shelter for each zone could be determined.

119. If the variation in risk discussed above, that is from area to area and from zone to zone within a single area, were taken into account in determining the optimum shelter design for each area and zone, then the result would be a number of optimum designs for each type of shelter, each applicable to a particular degree of risk. It is quite certain that such a differentiated policy would save more lives for a given expenditure than would the application of a single standard to all areas where shelter was provided. A substantial amount of work would, however, have to be undertaken to determine the magnitude of this extra saving in life, and it is at present impossible to forecast whether the saving would be sufficient to compensate for the political and morale objections to a differentiated shelter policy.

PART FIVE

RECOMMENDATIONS FOR FUTURE STUDIES

I. Shelter provision relative to risk

120. The conclusions reached in this study are based on the assumption of equal risk in all areas where shelter is provided, and on this basis a single 'optimum' standard for each type of shelter is recommended. It is possible that a greater saving in life for a given expenditure could be achieved by recognising that the risk is not in fact uniform in all shelter areas, by dividing these areas up into a number of 'risk' categories, and by determining the optimum standard corresponding to each degree of risk. The point is, of course, that it may not be worth while (in terms of cost per life saved) to build optimum shelters in the lower risk areas until something better than optimum has been provided in the higher risk areas.

121. This approach, of trying to relate the standard of protection in any area to the degree of risk in that area, has not been followed up in the present paper. It may, however, lead to a shelter policy which leaves many people in the 'shelter areas' without shelter unless the overall cost of the programme is increased.

122. The objections from a morale point of view of reducing the number of people for whom shelter is provided in order to pay for better shelters for those in the higher risk areas have to be weighed against the extra saving in life that would result from this policy. A considerable amount of work would have to be done before any estimate could be made of the likely magnitude of this extra saving. This work would have to be put in hand if the best theoretical solution of the shelter problem were desired, but if the practical objections to having shelter of varying standards in different areas are so strong that such a policy could not be adopted, than the work would be of only theoretical interest, and other shelter studies should be given priority.

II. Design considerations

123. The methods used for designing the shelters in the present series against blast - designing them against a uniformly distributed static load on the roof and sides of one seventh of the estimated peak blast pressure - cannot be considered satisfactory or final. The analysis of the results of past atomic trials and other tests, and the planning of future tests to yield the required data are being pursued in an attempt to devise a more satisfactory design procedure. Design against gamma radiation, although probably resting on a rather sounder theoretical basis than design against blast, cannot be considered final. In particular the analysis of those aspects of the recent atomic trials in Australia which bear on this aspect should be given priority.

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[*] United States Federal Civil Defence Adminstration Report No. TM-8-1 "Civil Defence Urban Analysis".

124. The most important type of shelter omitted from the present studies is perhaps the Anderson shelter, and an extension of the safety rating - cost analysis to the Anderson shelter should be undertaken.

125. The Anderson shelter was designed long before the atomic bomb was invented, and even before any real experience of the effects of H.E. bombs was available. It would be surprising, therefore, if the present design represented the most efficient (on a safety-cost basis) possible design of back garden shelter. It is for consideration, therefore, whether, in the light of present knowledge of the effects of atomic bombs and with possible help from future trials, an attempt should be made to design a more efficient back-garden shelter.

126. A number of extensions to the present studies have been suggested in this report, and these should be undertaken. The most important of these are the possibility of designing aurface shelters to carry a load of 1400 lb/sq.ft. with roofs thinner than 12 ins. the balance of the roof protection being made up with earth, and an extension of the surface and trench shelter studies to design loads greater than 1400 lb/sq.ft.

III. Costs and resources studies

127. The present studies have been confined to a single size and lay-out of surface and trench shelter. For a given strength and thickness it can probably be assumed that atomic safety is independent of size and shape, but the costs of other sizes and shapes should be determined.

128. Basements in buildings appear to offer possibilities of providing reasonable shelter at comparatively small cost, and the safety/cost relationship for a number of basements in both framed and unframed buildings, improved and strengthened to various degrees, should be investigated.

129. If safety and cost (in terms of £.s.d.) were the only criteria of a shelter programme, then extensions of the present studies on the lines outlined above should provide all the information necessary to devise an efficient shelter policy. However in an emergency of the type envisaged, a substantial proportion of the resources of the country will be available to build as many shelters as possible in a limited warning period. The true criterion will not be cost in terms of £.s.d, but cost in terms of labour and materials. The best method of shelter provision will be that which produces the greatest number of good shelters out of the available pool of labour and materials. An estimate must therefore be made of the probable size of that pool in the likely warning period, and any proposed shelter programme must be measured against it. It is possible that a programme based on the present studies would make excessive demands on certain materials (e.g. steel and cement) and on certain skills (e.g. the various trades associated with building in-situ reinforced concrete.)

APPENDIX

TABLE 1

Distance-risk rates for gamma radiation

Shelter Side-on: Unshielded

Thickness of roof and walls	Distance from G.Z. (yards)	⅜ mile burst			¼ mile burst			⅛ mile burst			Ground level burst		
		Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total
12 inches	50	0	.96	.96	0	.94	.94	0	.89	.89	1.0	0	1.0
	150	0	.89	.89	0	.83	.83	.34	.66	1.0	1.0	0	1.0
	250	0	.81	.81	.28	.72	1.0	.56	.44	1.0	1.0	0	1.0
	350	0	.73	.73	.40	.60	1.0	.69	.31	1.0	1.0	0	1.0
	450	0	.66	.66	.51	.49	1.0	.76	.24	1.0	1.0	0	1.0
	550	.04	.34	.38	.60	.40	1.0	.80	0	.80	1.0	0	1.0
	650	0	.02	.02	.66	.03	.69	.83	0	.83	1.0	0	1.0
	750				.62	0	.62	.85	0	.85	1.0	0	1.0
	850				.28	0	.28	.88	0	.88	1.0	0	1.0
	950							.41	0	.41	0.72	0	.72
	1050							.02	0	.02	.14	0	.14
15 inches	50	0	.96	.96	0	.94	.94	0	.89	.89	1.0	0	1.0
	150	0	.89	.89	0	.83	.83	.34	.66	1.0	1.0	0	1.0
	250	0	.81	.81	.11	.72	.83	.56	.44	1.0	1.0	0	1.0
	350	0	.73	.73	.40	.60	1.0	.69	.31	1.0	1.0	0	1.0
	450	0	.32	.32	.51	.49	1.0	.76	0	.76	1.0	0	1.0
	550				.60	.05	.65	.80	0	.80	1.0	0	1.0
	650				.42	0	.42	.83	0	.83	1.0	0	1.0
	750				.16	0	.16	.85	0	.85	1.0	0	1.0
	850							.39	0	.39	.83	0	.83
	950										.20	0	.20
18 inches	50	0	.96	.96	0	.94	.94	0	.89	.89	1.0	0	1.0
	150	0	.89	.89	0	.83	.83	.34	.66	1.0	1.0	0	1.0
	250	0	.81	.81	0	.72	.72	.56	.44	1.0	1.0	0	1.0
	350	0	.31	.31	.10	.60	.70	.69	.19	.88	1.0	0	1.0
	450				.20	.14	.34	.76	0	.76	1.0	0	1.0
	550				.17	0	.17	.80	0	.80	1.0	0	1.0
	650				.03	0	.03	.83	0	.83	1.0	0	1.0
	750							.46	0	.46	.88	0	.88
	850							.02	0	.02	.22	0	.22
24 inches	50	0	.34	.34	0	.94	.94	0	.89	.89	1.0	0	1.0
	150	0	.20	.20	0	.83	.83	.34	.66	1.0	1.0	0	1.0
	250				0	.66	.66	.56	.44	1.0	1.0	0	1.0
	350				0	.03	.03	.69	0	.69	1.0	0	1.0
	450							.76	0	.76	1.0	0	1.0
	550							.46	0	.46	1.0	0	1.0
	650							.07	0	.07	.45	0	.45

APPENDIX

TABLE 2

Distance-risk rates for gamma radiation
Shelter side-on; shielded by a building
20 ft. high at a distance of 30 ft.

Thickness of roof and walls	Distance from G.Z. (yards)	$\frac{3}{8}$ mile burst			$\frac{1}{4}$ mile burst			$\frac{1}{8}$ mile burst		
		Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total
12 inches	50	0	.96	.96	0	.94	.94	0	.89	.89
	150	0	.89	.89	0	.83	.83	.34	.66	1.0
	250	0	.81	.81	.28	.72	1.0	.56	.44	1.0
	350	0	.73	.73	.40	.60	1.0	.69	.31	1.0
	450	0	.66	.66	.51	.49	1.0	.76	.24	1.0
	550	.04	.34	.38	.60	.40	1.0	.78	0	.78
	650	0	.02	.02	.66	.03	.69	.25	0	.25
	750				.53	0	.53			
	850				.14	0	.14			
15 inches	50	0	.96	.96	0	.94	.94	0	.89	.89
	150	0	.89	.89	0	.83	.83	.34	.66	1.0
	250	0	.81	.81	.11	.72	.83	.56	.44	1.0
	350	0	.73	.73	.40	.60	1.0	.69	.31	1.0
	450	0	.32	.32	.51	.49	1.0	.76	0	.76
	550				.60	.05	.65	.25	0	.25
	650				.42	0	.42			
	750				.13	0	.13			
18 inches	50	0	.96	.96	0	.94	.94	0	.89	.89
	150	0	.89	.89	0	.83	.83	.34	.66	1.0
	250	0	.81	.81	0	.72	.72	.56	.44	1.0
	350	0	.31	.31	.10	.60	.70	.69	.19	.88
	450				.20	.14	.34	.45	0	.45
	550				.17	0	.17			
	650				.03	0	.03			
24 inches	50	0	.34	.34	0	.94	.94	0	.89	.89
	150	0	.20	.20	0	.83	.83	.34	.66	1.0
	250				0	.66	.66	.56	.44	1.0
	350				0	.03	.03	.68	0	.68
	450							.25	0	.25

TABLE 3

Distance-risk rates for gamma radiation
Shelter side-on; shielded by a building 50 ft.
high, at a distance of 20 ft.

Thickness of roof and walls	Distance from G.Z. (yards)	$\frac{3}{8}$ mile burst			$\frac{1}{4}$ mile burst			$\frac{1}{8}$ mile burst		
		Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total
12 inches	50	0	.96	.96	0	.94	.94	0	.89	.89
	150	0	.89	.89	0	.83	.83	.34	.66	1.0
	250	0	.81	.81	0	.72	.72	.56	.44	1.0
	350	0	.30	.30	0	.42	.42	.15	0	.15
15 inches	50	0	.96	.96	0	.94	.94	0	.89	.89
	150	0	.89	.89	0	.83	.83	.34	.66	1.0
	250	0	.81	.81	0	.61	.61	.29	.44	.73
	350	0	.30	.30	0	.03	.03			
18 inches	50	0	.96	.96	0	.94	.94	0	.89	.89
	150	0	.89	.89	0	.83	.83	.15	.66	.81
	250	0	.81	.81	0	.27	.27	.26	.32	.58
	350	0	.13	.13						
24 inches	50	0	.34	.34	0	.94	.94	0	.89	.89
	150	0	.20	.20	0	.83	.83	0	.66	.66
	250				0	.11	.11			

APPENDIX

TABLE 4

Distance-risk rates for gamma radiation

Shelter End-on; Unshielded

Thickness of roof and walls	Distance from G.Z. (yards)	⅜ mile burst			¼ mile burst			⅛ mile burst			Ground level burst		
		Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total
12 inches	50	0	.992	.992	0	.989	.989	0	.977	.977	1.0	0	1.0
	150	0	.977	.977	0	.966	.966	.068	.932	1.0	1.0	0	1.0
	250	0	.962	.962	.016	.943	.959	.114	.886	1.0	1.0	0	1.0
	350	0	.947	.947	.023	.920	.943	.159	.841	1.0	1.0	0	1.0
	450	.001	.932	.933	.029	.898	.927	.204	.796	1.0	1.0	0	1.0
	550	.002	.550	.552	.036	.875	.911	.175	0	.175	1.0	0	1.0
	650	0	.054	.054	.043	.077	.120	.095	0	.095	.63	0	.63
	750				.043	0	.043	.098	0	.098	.286	0	.286
	850				.020	0	.020	.110	0	.110	.286	0	.286
	950							.057	0	.057	.206	0	.206
	1050							.003	0	.003	.043	0	.043
15 inches	50	0	.992	.992	0	.989	.989	0	.977	.977	1.0	0	1.0
	150	0	.977	.977	0	.966	.966	.019	.932	.951	1.0	0	1.0
	250	0	.962	.962	.006	.943	.949	.065	.886	.951	1.0	0	1.0
	350	0	.947	.947	.023	.920	.943	.084	.841	.925	1.0	0	1.0
	450	0	.456	.456	.029	.898	.927	.068	0	.068	1.0	0	1.0
	550				.036	.105	.141	.071	0	.071	.42	0	.42
	650				.027	0	.027	.085	0	.085	.286	0	.286
	750				.011	0	.011	.098	0	.098	.286	0	.286
	850							.049	0	.049	.229	0	.229
	950										.057	0	.057
18 inches	50	0	.992	.992	0	.989	.989	0	.977	.977	1.0	0	1.0
	150	0	.977	.977	0	.966	.966	.019	.932	.951	1.0	0	1.0
	250	0	.962	.962	0	.943	.943	.033	.886	.919	1.0	0	1.0
	350	0	.407	.407	.006	.920	.926	.045	.522	.567	.950	0	.950
	450				.011	.26	.271	.059	.0	.059	.286	0	.286
	550				.010	0	.010	.071	0	.071	.286	0	.286
	650				.002	0	.002	.085	0	.085	.286	0	.286
	750							.052	0	.052	.252	0	.252
	850							.002	0	.002	.069	0	.069
24 inches	50	0	.337	.337	0	.989	.989	0	.977	.977	1.0	0	1.0
	150	0	.195	.195	0	.966	.966	.019	.932	.951	1.0	0	1.0
	250				0	.866	.866	.033	.886	.919	.286	0	.286
	350				0	.046	.046	.045	0	.045	.286	0	.286
	450							.059	0	.059	.286	0	.286
	550							.045	0	.045	.286	0	.286
	650							.004	0	.004	.129	0	.129

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APPENDIX

TABLE 5

DEATHS IN SURFACE SHELTERS

UNSHIELDED

Design blast pressure (lb/sq.ft.)	12" Shelter			15" Shelter			18" Shelter			24" Shelter		
	Orientation	Ht. of burst	Deaths	Orientation	Ht. of burst	Deaths	Orientation	Ht. of burst	Deaths	Orientation	Ht. of burst	Deaths
1400	Side-on	0	27,560	Side-on	0	23,140	Side-on	0	18,520	Side-on	0	11,840
		1/8	22,510		1/8	19,410		1/8	14,550		1/8	8,260
		1/4	16,690		1/4	11,270		1/4	6,030		1/4	4,100
		3/8	6,540		3/8	4,430		3/8	2,780		3/8	270
	Weighted mean		18,840	Weighted mean		14,870	Weighted mean		10,400	Weighted mean		6,140
	End-on	0	16,500	End-on	0	12,050	End-on	0	9,010	End-on	0	7,000
		1/8	9,210		1/8	6,560		1/8	6,050		1/8	5,380
		1/4	10,430		1/4	7,440		1/4	5,440		1/4	4,100
		3/8	8,610		3/8	5,500		3/8	3,280		3/8	260
	Weighted mean		10,640	Weighted mean		7,530	Weighted mean		5,860	Weighted mean		4,410
	Mean of end-on and side-on		14,740	Mean of end-on and side-on		11,200	Mean of end-on and side-on		8,130	Mean of end-on and side-on		5,270
1000	Side-on	0	27,560	Side-on	0	23,140	Side-on	0	18,520			
		1/8	22,650		1/8	19,410		1/8	14,790			
		1/4	16,690		1/4	11,390		1/4	7,370			
		3/8	6,660		3/8	4,520		3/8	2,920			
	Weighted mean		18,900	Weighted mean		14,930	Weighted mean		10,970			
	End-on	0	16,500	End-on	0	12,150	End-on	0	10,270			
		1/8	9,520		1/8	8,010		1/8	7,550			
		1/4	10,590		1/4	7,910		1/4	6,760			
		3/8	8,620		3/8	5,510		3/8	3,340			
	Weighted mean		10,800	Weighted mean		8,220	Weighted mean		7,050			
	Mean of end-on and side-on		14,850	Mean of end-on and side-on		11,570	Mean of end-on and side-on		9,010			
500	Side-on	0	27,560	Side-on	0	23,140						
		1/8	23,310		1/8	19,500						
		1/4	18,210		1/4	15,340						
		3/8	14,810		3/8	14,300						
	Weighted mean		20,890	Weighted mean		17,810						
	End-on	0	16,860	End-on	0	14,560						
		1/8	14,210		1/8	13,640						
		1/4	14,820		1/4	14,510						
		3/8	15,110		3/8	14,390						
	Weighted mean		14,950	Weighted mean		14,190						
	Mean of end-on and side-on		17,920	Mean of end-on and side-on		16,000						
No blast deaths	Side-on	0	27,560	Side-on	0	23,140	Side-on	0	18,640	Side-on	0	11,840
		1/8	22,730		1/8	17,450		1/8	13,780		1/8	7,500
		1/4	16,530		1/4	10,910		1/4	4,870		1/4	1,960
		3/8	6,550		3/8	4,430		3/8	2,780		3/8	270
	Weighted mean		18,860	Weighted mean		14,060	Weighted mean		9,740	Weighted mean		5,130
	End-on	0	16,500	End-on	0	12,050	End-on	0	8,490	End-on	0	4,200
		1/8	9,210		1/8	5,640		1/8	4,420		1/8	2,760
		1/4	10,230		1/4	7,240		1/4	4,990		1/4	2,410
		3/8	8,610		3/8	5,500		3/8	3,280		3/8	260
	Weighted mean		10,580	Weighted mean		7,140	Weighted mean		5,060	Weighted mean		2,490
	Mean of end-on and side-on		14,720	Mean of end-on and side-on		10,600	Mean of end-on and side-on		7,400	Mean of end-on and side-on		3,810

APPENDIX

TABLE 6

DEATHS IN SURFACE SHELTERS

MODERATELY SHIELDED (SHIELDING ANGLE 17° – 51°)

Design blast pressure (lb/sq.ft.)	12" Shelter			15" Shelter			18" Shelter			24" Shelter		
	Orientation	Ht. of burst	Deaths	Orientation	Ht. of burst	Deaths	Orientation	Ht. of burst	Deaths	Orientation	Ht. of burst	Deaths
1400	Side-on	0	5,060	Side-on	0	5,060	Side-on	0	5,060	Side-on	0	5,060
		1/8	10,420		1/8	7,410		1/8	6,080		1/8	5,710
		1/4	15,640		1/4	11,160		1/4	6,030		1/4	4,100
		3/8	6,540		3/8	4,430		3/8	2,780		3/8	270
	Weighted mean		10,870	Weighted mean		7,930	Weighted mean		5,440	Weighted mean		4,250
	End-on	0	16,500	End-on	0	12,050	End-on	0	9,010	End-on	0	7,000
		1/8	9,210		1/8	6,560		1/8	6,050		1/8	5,380
		1/4	10,430		1/4	7,440		1/4	5,440		1/4	4,100
		3/8	8,610		3/8	5,500		3/8	3,280		3/8	260
	Weighted mean		10,640	Weighted mean		7,530	Weighted mean		5,860	Weighted mean		4,410
	Mean of end-on and side-on		10,750	Mean of end-on and side-on		7,730	Mean of end-on and side-on		5,650	Mean of end-on and side-on		4,330
1000	Side-on	0	6,860	Side-on	0	6,860	Side-on	0	6,860			
		1/8	10,510		1/8	7,980		1/8	7,090			
		1/4	15,640		1/4	11,340		1/4	7,370			
		3/8	6,620		3/8	4,520		3/8	2,920			
	Weighted mean		11,180	Weighted mean		8,480	Weighted mean		6,540			
	End-on	0	16,500	End-on	0	12,150	End-on	0	10,270			
		1/8	9,520		1/8	8,010		1/8	7,550			
		1/4	10,590		1/4	7,910		1/4	6,760			
		3/8	8,620		3/8	5,510		3/8	3,340			
	Weighted mean		10,800	Weighted mean		8,220	Weighted mean		7,050			
	Mean of end-on and side-on		10,990	Mean of end-on and side-on		8,350	Mean of end-on and side-on		6,800			
500	Side-on	0	11,270	S'de-on	0	11,270						
		1/8	13,360		1/8	13,100						
		1/4	17,370		1/4	15,330						
		3/8	14,810		3/8	14,300						
	Weighted mean		14,670	Weighted mean		13,780						
	End-on	0	16,860	End-on	0	14,560						
		1/8	14,210		1/8	13,640						
		1/4	14,820		1/4	14,510						
		3/8	15,110		3/8	14,390						
	Weighted mean		14,950	Weighted mean		14,190						
	Mean of end-on and side-on		14,810	Mean of end-on and side-on		13,990						
No blast deaths	Side-on	0	0	Side-on	0	0	Side-on	0	0	Side-on	0	0
		1/8	10,390		1/8	7,210		1/8	5,400		1/8	4,500
		1/4	15,470		1/4	10,790		1/4	4,870		1/4	1,960
		3/8	6,550		3/8	4,430		3/8	2,780		3/8	270
	Weighted mean		10,040	Weighted mean		6,960	Weighted mean		4,010	Weighted mean		2,300
	End-on	0	16,500	End-on	0	12,050	End-on	0	8,490	End-on	0	4,200
		1/8	9,210		1/8	5,640		1/8	4,420		1/8	2,760
		1/4	10,230		1/4	7,240		1/4	4,990		1/4	2,410
		3/8	8,610		3/8	5,500		3/8	3,280		3/8	260
	Weighted mean		10,580	Weighted mean		7,140	Weighted mean		5,060	Weighted mean		2,490
	Mean of end-on and side-on		10,310	Mean of end-on and side-on		7,050	Mean of end-on and side-on		4,540	Mean of end-on and side-on		2,400

APPENDIX

TABLE 7

DEATHS IN SURFACE SHELTERS

WELL SHIELDED (SHIELDING ANGLE 51°)

Design blast pressure (lb/sq.in.)	12" Shelter			15" Shelter			18" Shelter			24" Shelter		
	Orientation	Ht. of burst	Deaths	Orientation	Ht. of burst	Deaths	Orientation	Ht. of burst	Deaths	Orientation	Ht. of burst	Deaths
1400	Side-on	0	5,060	Side-on	0	5,060	Side-on	0	5,060	Side-on	0	5,060
		1/8	5,130		1/8	5,110		1/8	5,110		1/8	5,110
		1/4	4,400		1/4	4,080		1/4	4,020		1/4	4,000
		3/8	2,760		3/8	2,760		3/8	2,330		3/8	270
	Weighted mean		4,510	Weighted mean		4,390	Weighted mean		4,310	Weighted mean		3,990
	End-on	0	16,500	End-on	0	12,050	End-on	0	9,010	End-on	0	7,000
		1/8	9,210		1/8	6,560		1/8	6,050		1/8	5,320
		1/4	10,430		1/4	7,440		1/4	5,440		1/4	4,100
		3/8	8,610		3/8	5,500		3/8	3,280		3/8	260
	Weighted mean		10,640	Weighted mean		7,530	Weighted mean		5,860	Weighted mean		4,410
	Mean of end-on and side-on		7,570	Mean of end-on and side-on		5,960	Mean of end-on and side-on		5,080	Mean of end-on and side-on		4,200
1000	Side-on	0	6,860	Side-on	0	6,860	Side-on	0	6,860			
		1/8	6,780		1/8	6,780		1/8	6,780			
		1/4	6,450		1/4	6,450		1/4	6,450			
		3/8	2,900		3/8	2,900		3/8	2,570			
	Weighted mean		6,100	Weighted mean		6,100	Weighted mean		6,050			
	End-on	0	16,500	End-on	0	12,150	End-on	0	10,270			
		1/8	9,520		1/8	8,010		1/8	7,550			
		1/4	10,590		1/4	7,910		1/4	6,760			
		3/8	8,620		3/8	5,510		3/8	3,340			
	Weighted mean		10,800	Weighted mean		8,220	Weighted mean		7,050			
	Mean of end-on and side-on		8,450	Mean of end-on and side-on		7,160	Mean of end-on and side-on		6,550			
500	Side-on	0	11,270	Side-on	0	11,270						
		1/8	12,890		1/8	12,890						
		1/4	14,440		1/4	14,440						
		3/8	14,130		3/8	14,130						
	Weighted mean		13,350	Weighted mean		13,380						
	End-on	0	16,860	End-on	0	14,560						
		1/8	14,210		1/8	13,640						
		1/4	14,820		1/4	14,510						
		3/8	15,110		3/8	14,390						
	Weighted mean		14,950	Weighted mean		14,190						
	Mean of end-on and side-on		14,150	Mean of end-on and side-on		13,780						
No blast deaths	Side-on	0	0	Side-on	0	0	Side-on	0	0	Side-on	0	0
		1/8	2,810		1/8	2,130		1/8	1,760		1/8	810
		1/4	2,820		1/4	1,890		1/4	1,350		1/4	1,130
		3/8	2,760		3/8	2,760		3/8	2,430		3/8	270
	Weighted mean		2,380	Weighted mean		1,820	Weighted mean		1,450	Weighted mean		720
	End-on	0	16,500	End-on	0	12,050	End-on	0	8,490	End-on	0	4,200
		1/8	9,210		1/8	5,640		1/8	4,420		1/8	2,760
		1/4	10,230		1/4	7,240		1/4	4,990		1/4	2,410
		3/8	8,610		3/8	5,500		3/8	3,280		3/8	260
	Weighted mean		10,580	Weighted mean		7,140	Weighted mean		5,060	Weighted mean		2,490
	Mean of end-on and side-on		6,480	Mean of end-on and side-on		4,480	Mean of end-on and side-on		3,250	Mean of end-on and side-on		1,600

APPENDIX

TABLE 8

Distance-risk rates for 1 MeV gamma radiation

Walls and roof of shelter 12 inches thick

Shelter position	Distance from G.Z. (yards)	⅜ mile burst			¼ mile burst			⅛ mile burst			Ground level burst		
		Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total
Side-on unshielded	50	0	.96	.96	0	.94	.94	0	.89	.89	1.0	0	1.0
	150	0	.71	.71	0	.83	.83	.34	.66	1.0	1.0	0	1.0
	250	0	.31	.31	0	.72	.72	.56	.44	1.0	1.0	0	1.0
	350				0	.27	.27	.69	0	.69	1.0	0	1.0
	450							.76	0	.76	1.0	0	1.0
	550							.80	0	.80	1.0	0	1.0
	650							.45	0	.45	1.0	0	1.0
	750							.04	0	.04	.36	0	.36
Side-on moderately shielded	50	0	.96	.96	0	.94	.94	0	.89	.89			
	150	0	.71	.71	0	.83	.83	.34	.66	1.0			
	250	0	.31	.31	0	.72	.72	.56	.44	1.0			
	350				0	.27	.27	.66	0	.66			
	450							.25	0	.25			
End-on unshielded	50	0	.992	.992	0	.989	.989	0	.977	.977	1.0	0	1.0
	150	0	.859	.859	0	.966	.966	.019	.932	.951	1.0	0	1.0
	250	0	.360	.366	0	.943	.943	.033	.886	.919	.493	0	.493
	350				0	.414	.414	.045	0	.045	.286	0	.286
	450							.059	0	.059	.286	0	.286
	550							.071	0	.071	.286	0	.286
	650							.046	0	.046	.286	0	.286
	750							.005	0	.005	.103	0	.103

APPENDIX

TABLE 9

Deaths due to blast and 1 MeV radiation in 12" surface shelters

Design Blast Pressure (lb/sq.ft.)	Orientation	Height of Burst (mile)	Unshielded	Moderately shielded	Subjected to blast only
1400	Side-on	0	13,850	5,190	5,190
		1/8	10,510	5,220	5,130
		1/4	4,300	4,300	3,990
		3/8	1,310	1,310	0
	Weighted mean		7,600	4,310	3,970
	End-on	0	8,100	8,100	As above
		1/8	5,650	5,650	
		1/4	4,440	4,440	
		3/8	1,560	1,560	
	Weighted mean		4,980	4,980	3,970
	Mean of side-on and end-on		6,290	4,640	3,970
1000	Side-on	0	13,850	6,950	6,950
		1/8	11,290	6,760	6,760
		1/4	6,410	6,410	6,400
		3/8	1,610	1,610	620
	Weighted mean		8,510	5,890	5,740
	End-on	0	9,370	9,370	As above
		1/8	7,190	7,190	
		1/4	6,420	6,420	
		3/8	1,790	1,790	
	Weighted mean		6,440	6,440	5,740
	Mean of side-on and end-on		7,480	6,160	5,740
500	Side-on	0	15,420	11,270	11,270
		1/8	13,910	13,060	13,060
		1/4	14,470	14,470	14,470
		3/8	14,090	14,090	14,090
	Weighted mean		14,350	13,440	13,440
	End-on	0	12,460	12,460	As above
		1/8	13,150	13,150	
		1/4	14,470	14,470	
		3/8	14,090	14,090	
	Weighted mean		13,650	13,650	13,440
	Mean of side-on and end-on		14,000	13,540	13,440
No blast deaths	Side-on	0	15,380	0	0
		1/8	10,120	4,460	0
		1/4	2,520	2,520	0
		3/8	1,310	1,310	0
	Weighted mean		6,930	2,640	0
	End-on	0	5,510	As unshielded	0
		1/8	2,760		0
		1/4	3,250		0
		3/8	1,530		0
	Weighted mean		3,160	3,160	0
	Mean of side-on and end-on		5,040	2,900	0

APPENDIX

TABLE 10

Distance-risk rates for gamma radiation
Trench shelters; end-on unshielded

Earth Cover (ft.)	Roof Thickness (in.)	Distance from G.Z. (yd.)	Gamma risk rate (roof)*		
			$\frac{3}{8}$ mile burst	$\frac{1}{4}$ mile burst	$\frac{1}{8}$ mile burst
1	7.5	0-250 350 450 550	1.0 1.0 .40	1.0 1.0 1.0 .03	1.0
	6	0-350 450 550	1.0 .75 .17	1.0 1.0 .38	1.0 .24
	5	0-350 450 550	1.0 1.0 .36	1.0 1.0 .69	1.0 .64
2	7.5	50 150 250 350	.44 .28	1.0 1.0 1.0 .10	1.0 1.0 1.0
	6	50 150 250 350	.75 .55 .22	1.0 1.0 1.0 .38	1.0 1.0 1.0
	5	50 150 250 350	1.0 .80 .41	1.0 1.0 1.0 .62	1.0 1.0 1.0
3	7.5	50 150	0	.75 .26	1.0 1.0
	6	50 150 250	0	1.0 .53	1.0 1.0 .09
5	7.5	50	0	0	.15
	6.5	50	0	0	.26

*Shelters assumed to be infinitely long and so all the radiation is received through the roof.

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APPENDIX

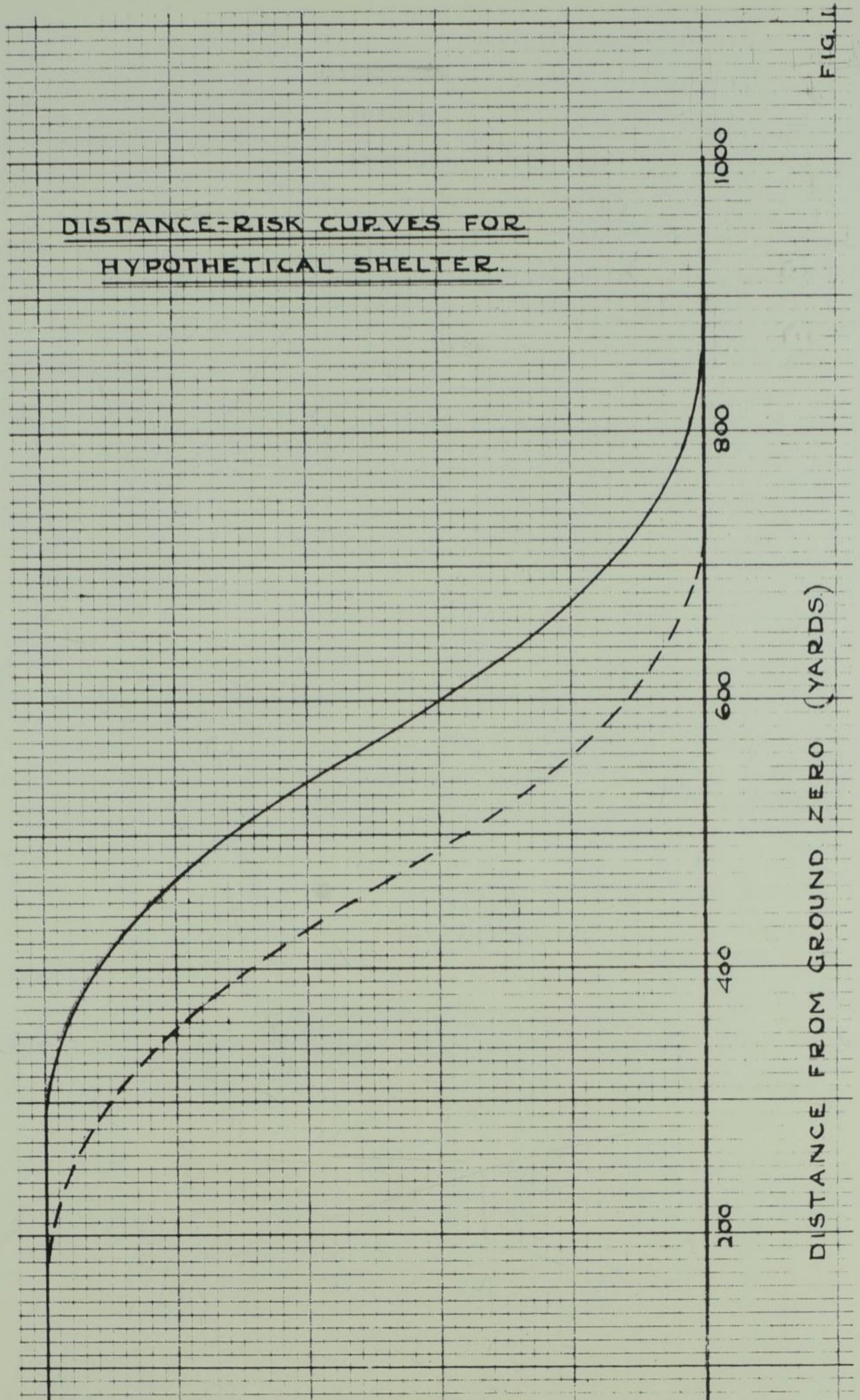
TABLE 11

Deaths in trench shelters; end-on; unshielded

Design blast pressure (lb/sq.ft.)	Height of Burst (mile)	Deaths for earth cover of depth:-			
		1 ft.	2 ft.	3 ft.	5 ft.
1400	0[+]	5190	5190	5190	5190
	$\frac{1}{8}$	5280	5130	5130	5130
	$\frac{1}{4}$	7160	4200	3990	3990
	$\frac{3}{8}$	5540	360	0	0
Weighted mean		5970	4100	3970[*]	3970[*]
1000	0[+]	6950	6950	6950	6950
	$\frac{1}{8}$	6940	6760	6760	6760
	$\frac{1}{4}$	8500	6400	6400	6400
	$\frac{3}{8}$	6960	1380	620	620
Weighted mean		7490	5860	5740[*]	5740[*]
500	0[+]	11270	11270	11270	
	$\frac{1}{8}$	13060	13060	13060	
	$\frac{1}{4}$	14500	14470	14470	
	$\frac{3}{8}$	15020	14090	14090	
Weighted mean		13590	13440[*]	13440[*]	
250	0[+]	23100			
	$\frac{1}{8}$	28180			
	$\frac{1}{4}$	31910			
	$\frac{3}{8}$	40360			
Weighted mean		30540[*]			
No blast deaths	0	0	0	0	0
	$\frac{1}{8}$	4520	2540	1130	10
	$\frac{1}{4}$	7160	2740	430	0
	$\frac{3}{8}$	5540	360	0	0
Weighted mean		4920	1900	550	0

[+] Assumed that for a ground burst there are no deaths due to gamma radiation

[*] No. of deaths the same as for blast alone.



DISTANCE-RISK CURVES FOR HYPOTHETICAL SHELTER.

FIG. I.

FIG I.

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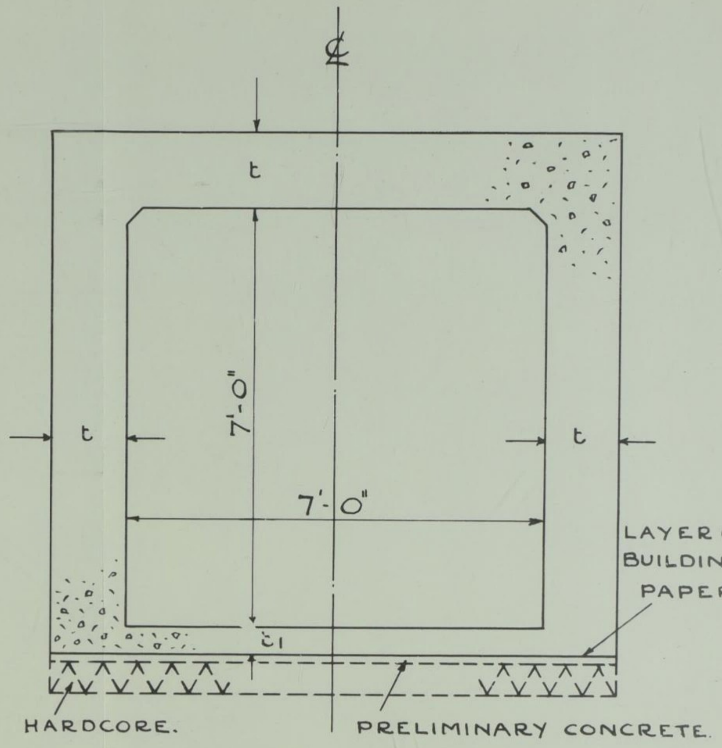
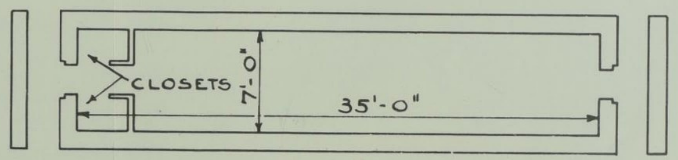
CASE NO.	BLAST LOAD	ROOF & WALL THICKNESS t (IN)	FLOOR THICKNESS t_1 (IN)	WT. OF REINFORCEMENT PER FT. RUN OF SHELTER (LB)	TOTAL WT. OF STEEL IN SHELTER (LB)
1	1400	12	5	46·2	2249
	1000	"	"	37·4	1840
	500	"	"	22·5	1155
	250	"	"	"	"
2	1400	15	5	44·3	2218
	1000	"	"	30·7	1578
	500	"	"	27·3	1427
	250	"	"	"	"
3	1400	18	5	41·7	2170
	1000	"	"	32·4	1747
	500	"	"	"	"
	250	"	"	"	"
4	1400	24	5	43·9	2411
	1000	"	"	"	"
	500	"	"	"	"
	250	"	"	"	"



CROSS SECTION.



PLAN

SURFACE SHELTERS.

FIG. 2.

SURFACE SHELTERS.

DISTANCE-RISK CURVES FOR BLAST
1400 lb/SQ. FT. DESIGN.

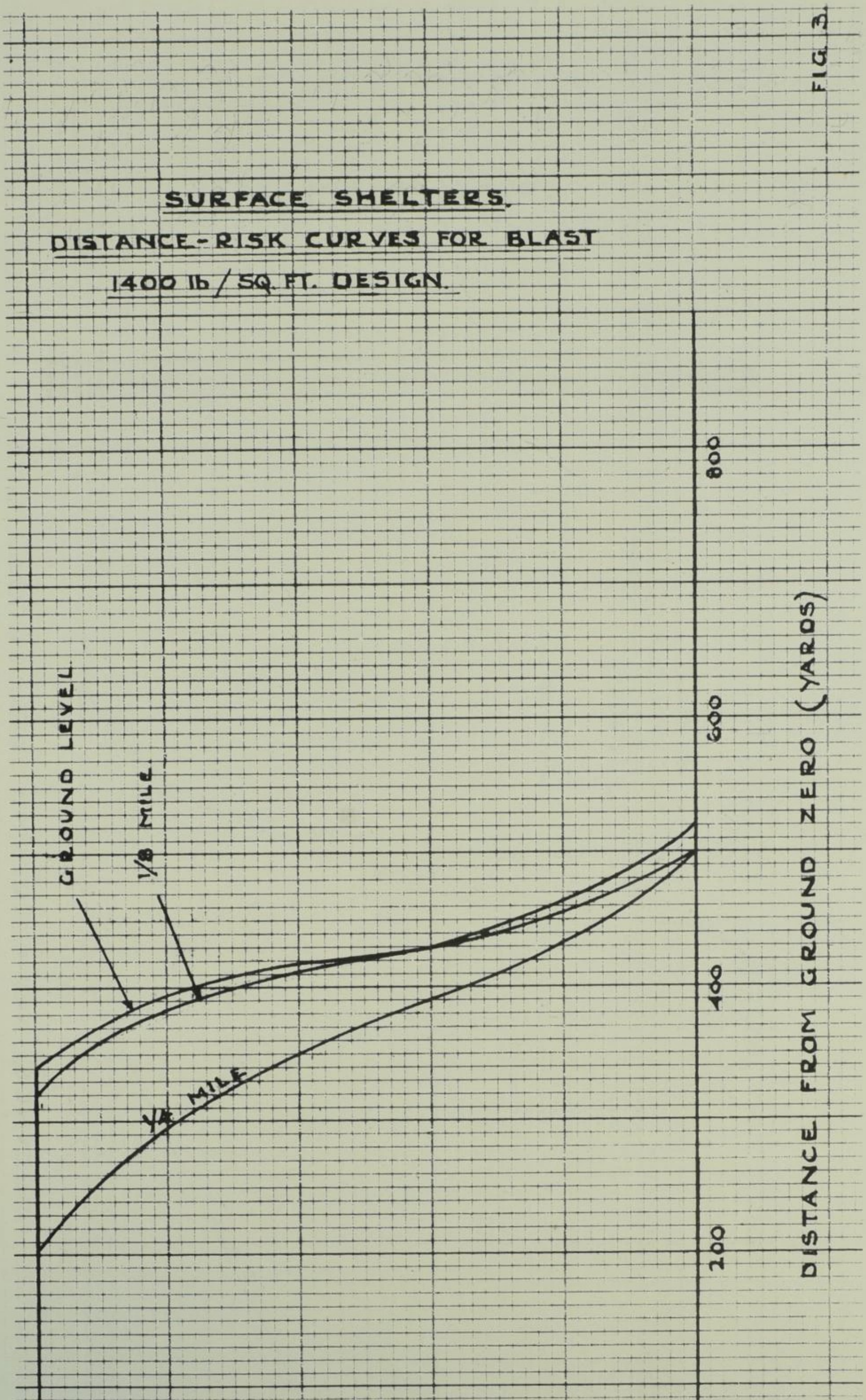


FIG. 3.

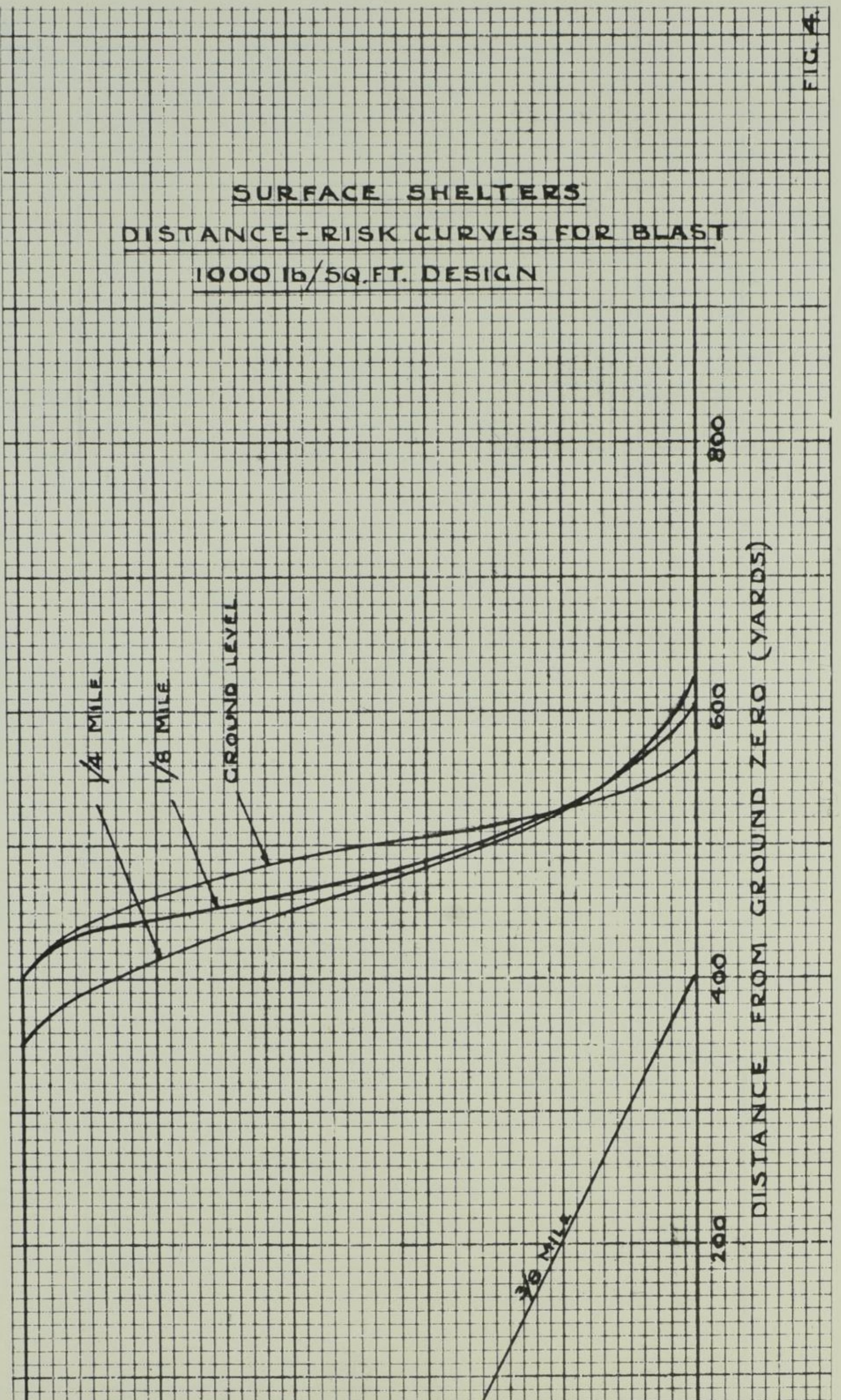

SURFACE SHELTERS
DISTANCE-RISK CURVES FOR BLAST
1000 lb/SQ.FT. DESIGN
1/4 MILE
1/8 MILE
GROUND LEVEL
3/8 MILE
PERCENTAGE DEATHS
100
80
60
40
20
0
DISTANCE FROM GROUND ZERO (YARDS)
200
400
600
800

FIG. 4.

FIG. 4.

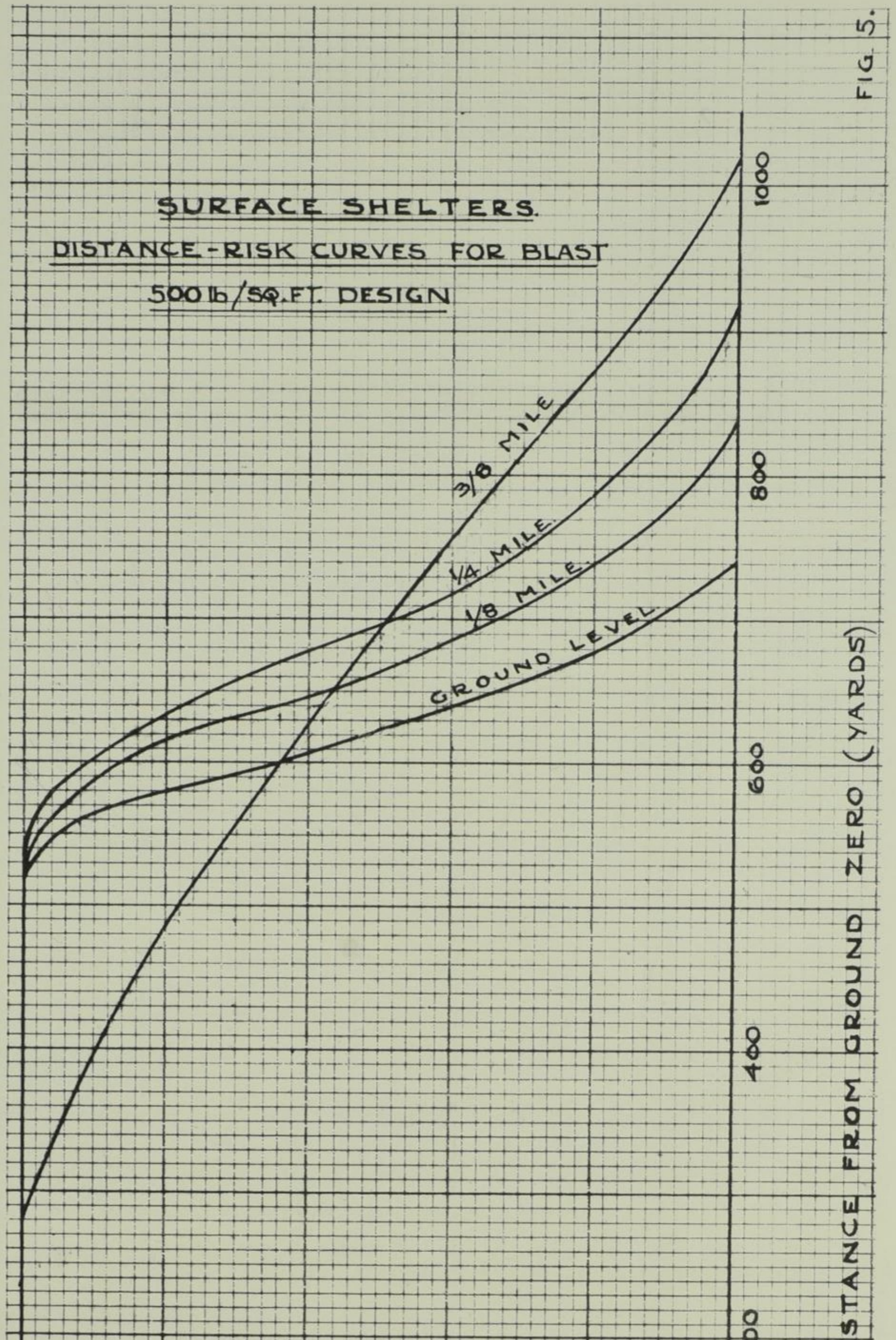

SURFACE SHELTERS.
DISTANCE-RISK CURVES FOR BLAST
500 lb/SQ.FT. DESIGN
3/8 MILE
1/4 MILE.
1/8 MILE.
GROUND LEVEL
DISTANCE FROM GROUND ZERO (YARDS)
1000
800
600
400
200
PERCENTAGE DEATHS
100
80
60
40
20
0

FIG. 5.

SAFETY-COST RELATIONSHIP FOR SURFACE SHELTERS.

(ROOF AND WALLS OF EQUAL THICKNESS.)

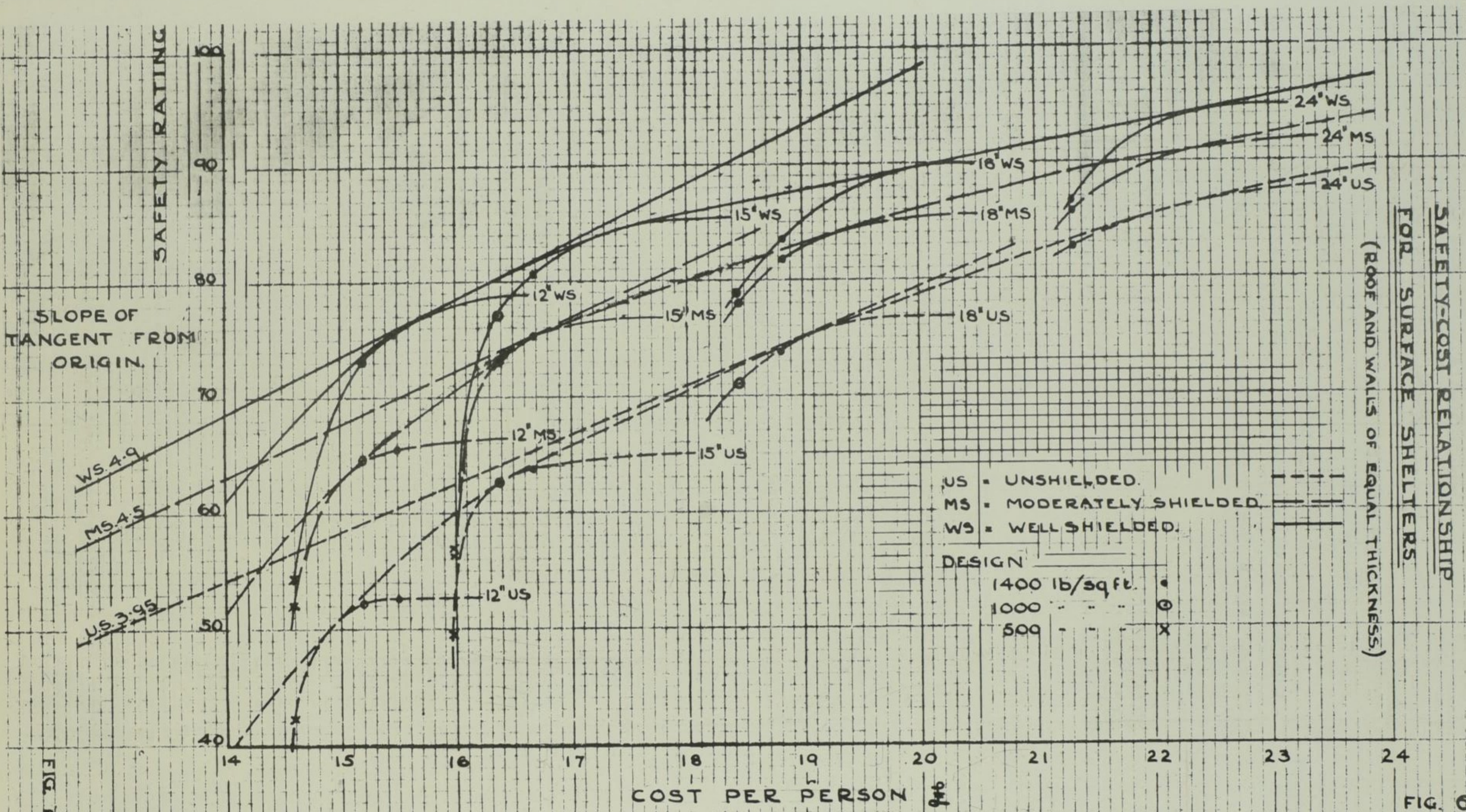


FIG. 6.

COMPARATIVE SAFETY-COST RATING FOR SURFACE SHELTERS.

FIG. 7.

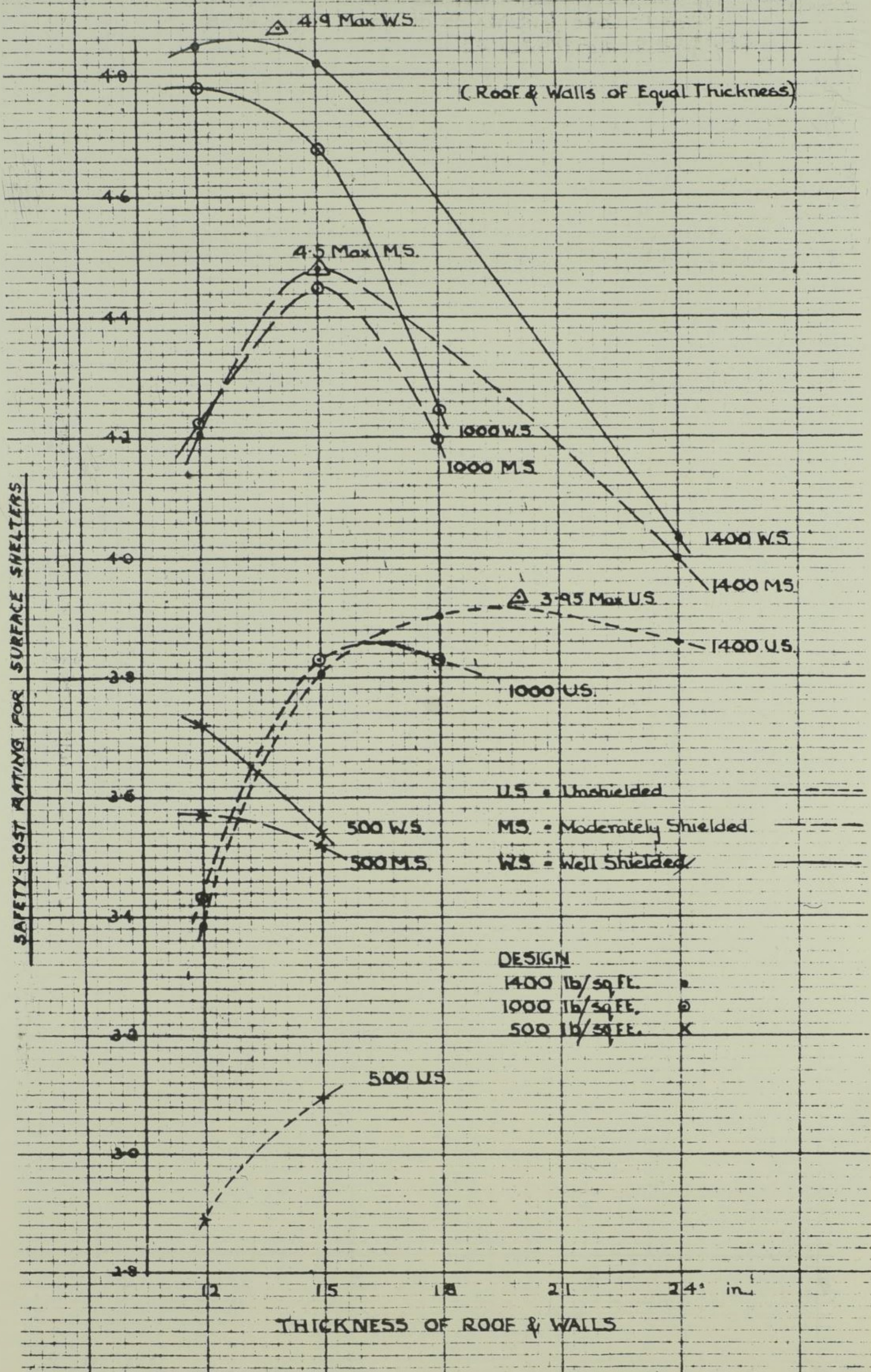
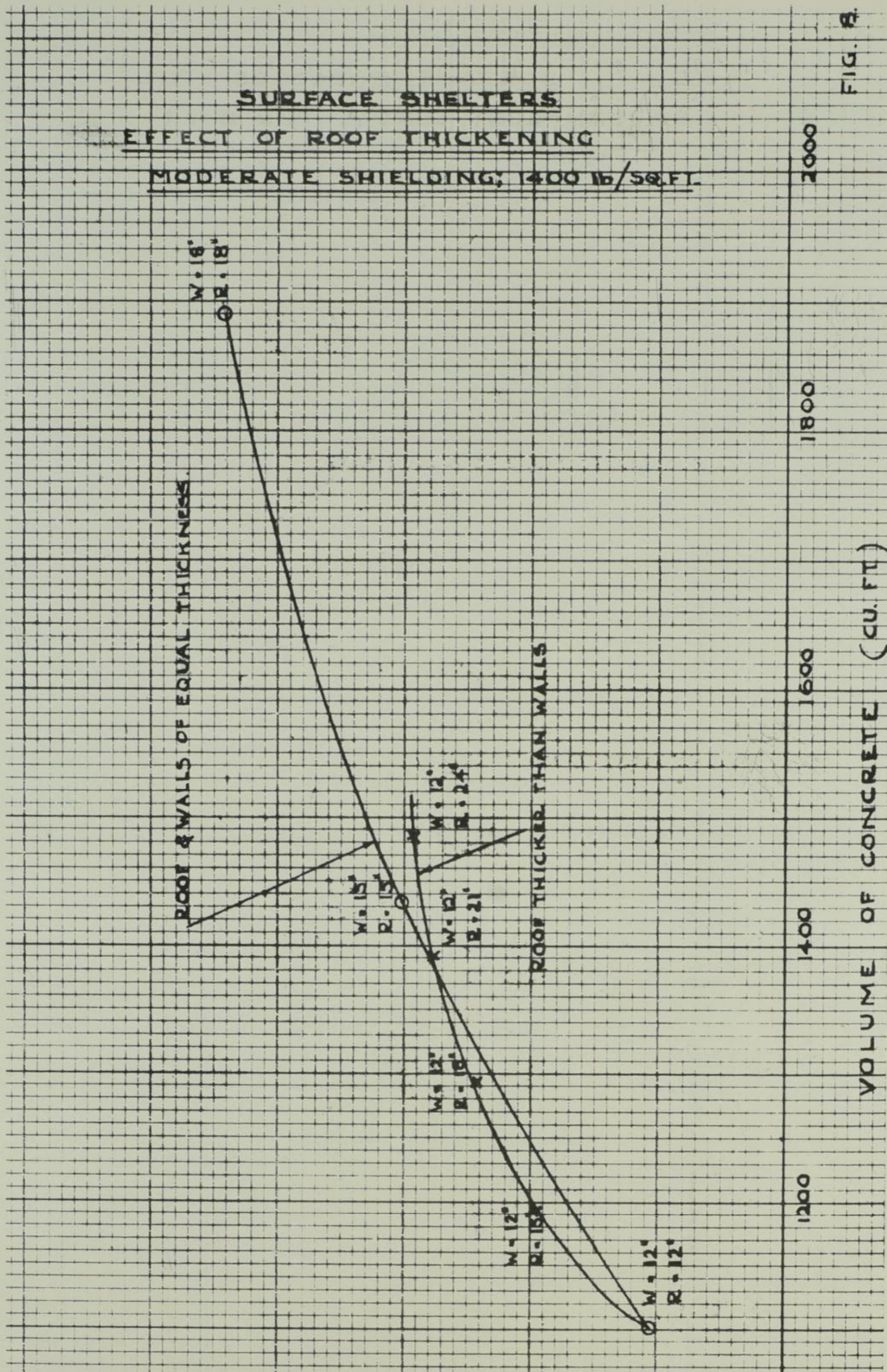


FIG. 7.

(19908)



SURFACE SHELTERS

EFFECT OF ROOF THICKENING

MODERATE SHIELDING; 1400 lb/SQ.FT.

FIG. 8.

FIG. 9.

SURFACE SHELTERS
SAFETY-COST CURVES FOR 8N BOMB
MODERATE SHIELDING

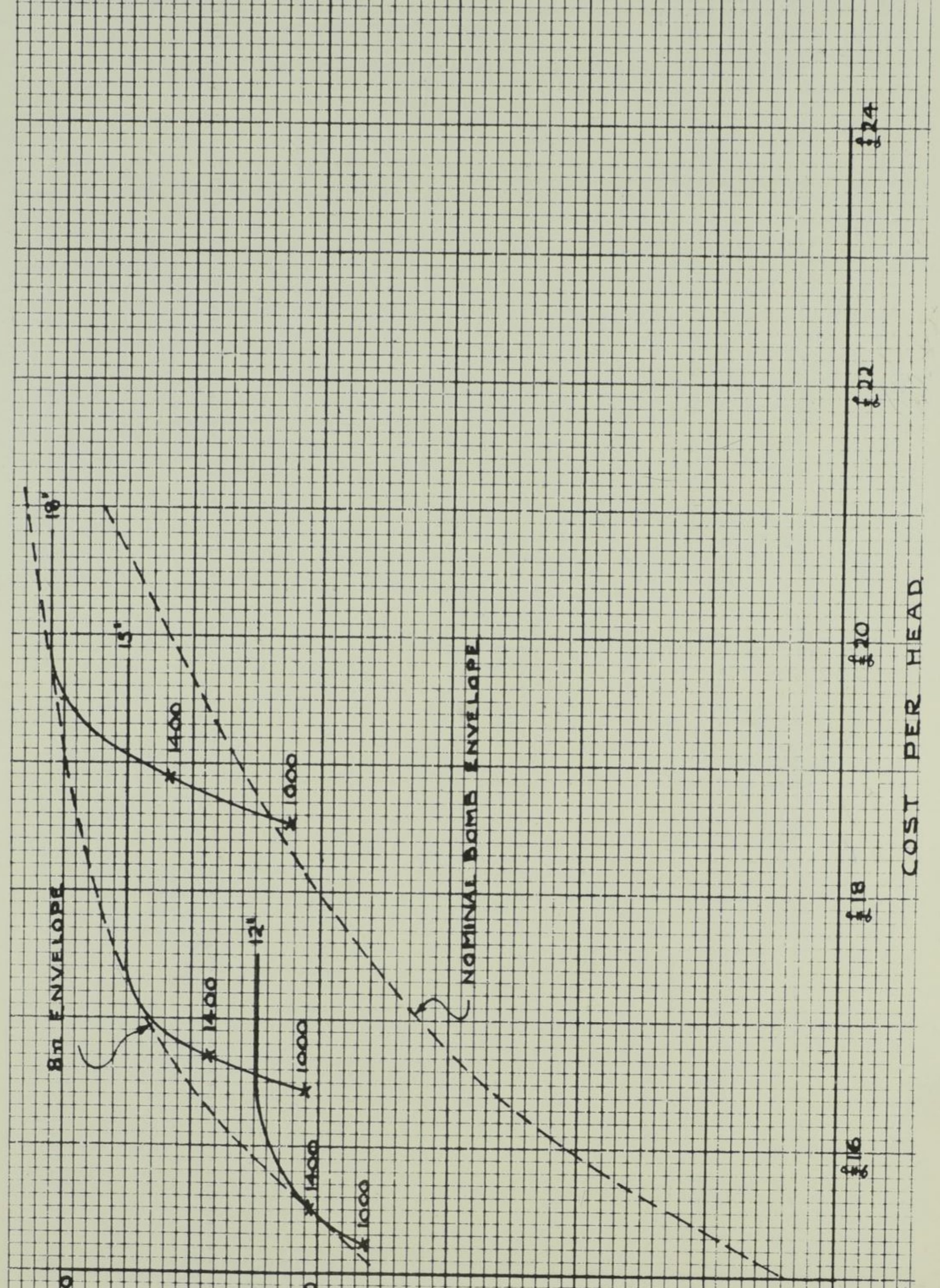
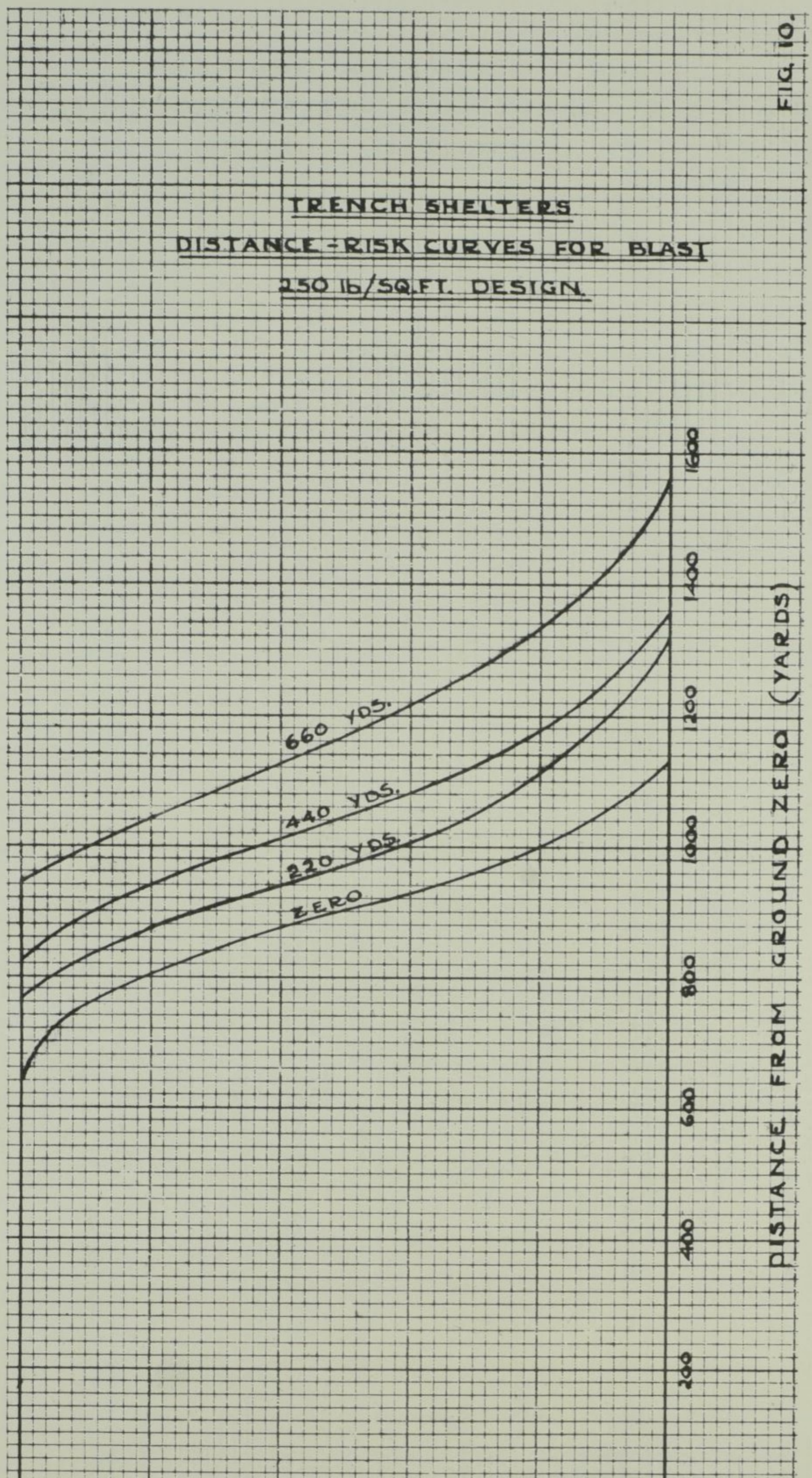


FIG. 9.

FIG. 10.

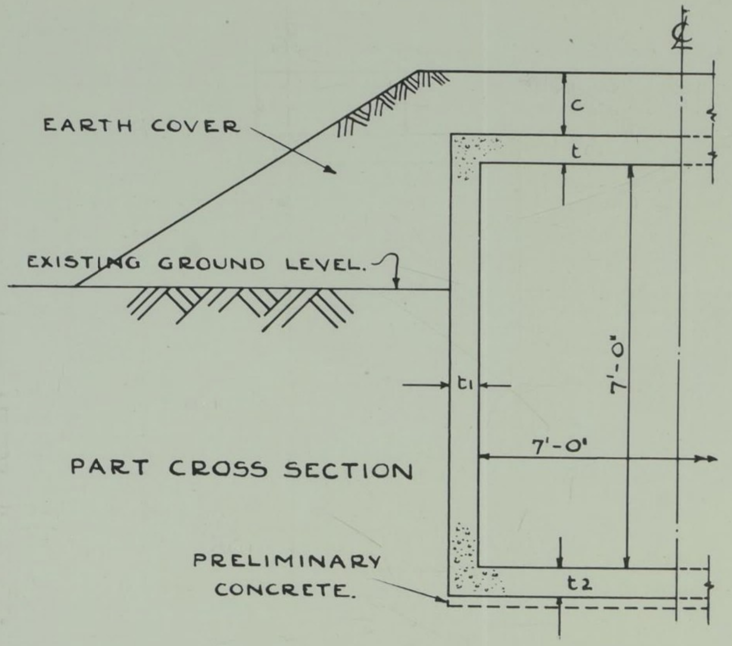


TRENCH SHELTERS

DISTANCE - RISK CURVES FOR BLAST

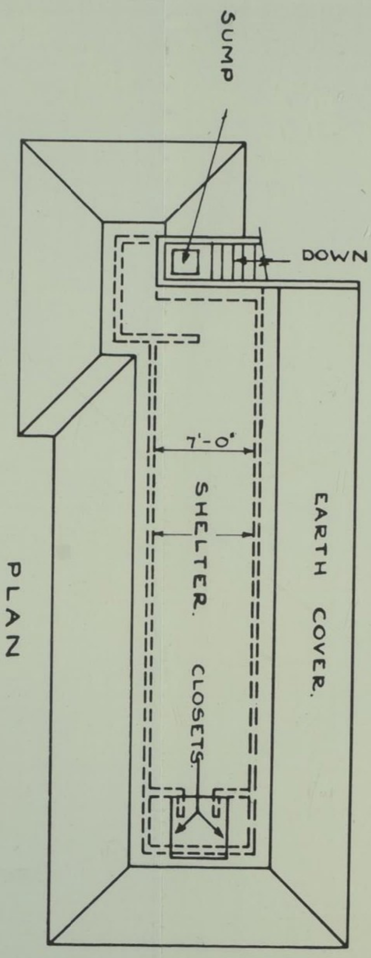
250 lb/SQ.FT. DESIGN.

FIG. 10.



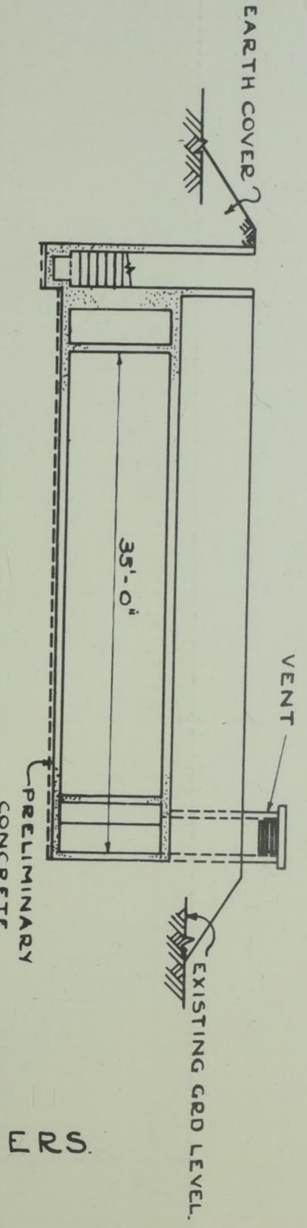
PART CROSS SECTION

CASE No.	BLAST LOAD	ROOF THICKNESS t (IN)	WALL THICKNESS t1 (IN)	FLOOR THICKNESS t2 (IN)	EARTH COVER 'C' FEET.	WT. OF REINFORCEMENT PER FT. RUN OF SHELTER (LB)	TOTAL WT OF STEEL IN SHELTER (LB)
1	1400	7½	5	5	1·0	46·9	2110
	1000	6	"	"	"	41·3	1896
	500	5	"	"	"	35·6	1701
	250	"	"	"	"	33·0	1606
2	1400	7½	5½	5½	2·0	51·7	2367
	1000	6	5	5	"	51·3	2352
	500	5	"	"	"	47·9	2237
	250	"	"	"	"	"	"
3	1400	7½	6	6	3·0	55·2	2593
	1000	6	"	"	"	53·1	2523
	500	"	"	"	"	50·0	2413
	250	"	"	"	"	"	"
4	1400	7½	6½	6½	5·0	65·6	3115
	1000	6½	"	"	"	63·0	3025
	500	"	"	"	"	"	"
	250	"	"	"	"	"	"



PLAN

SECTIONAL ELEVATION.

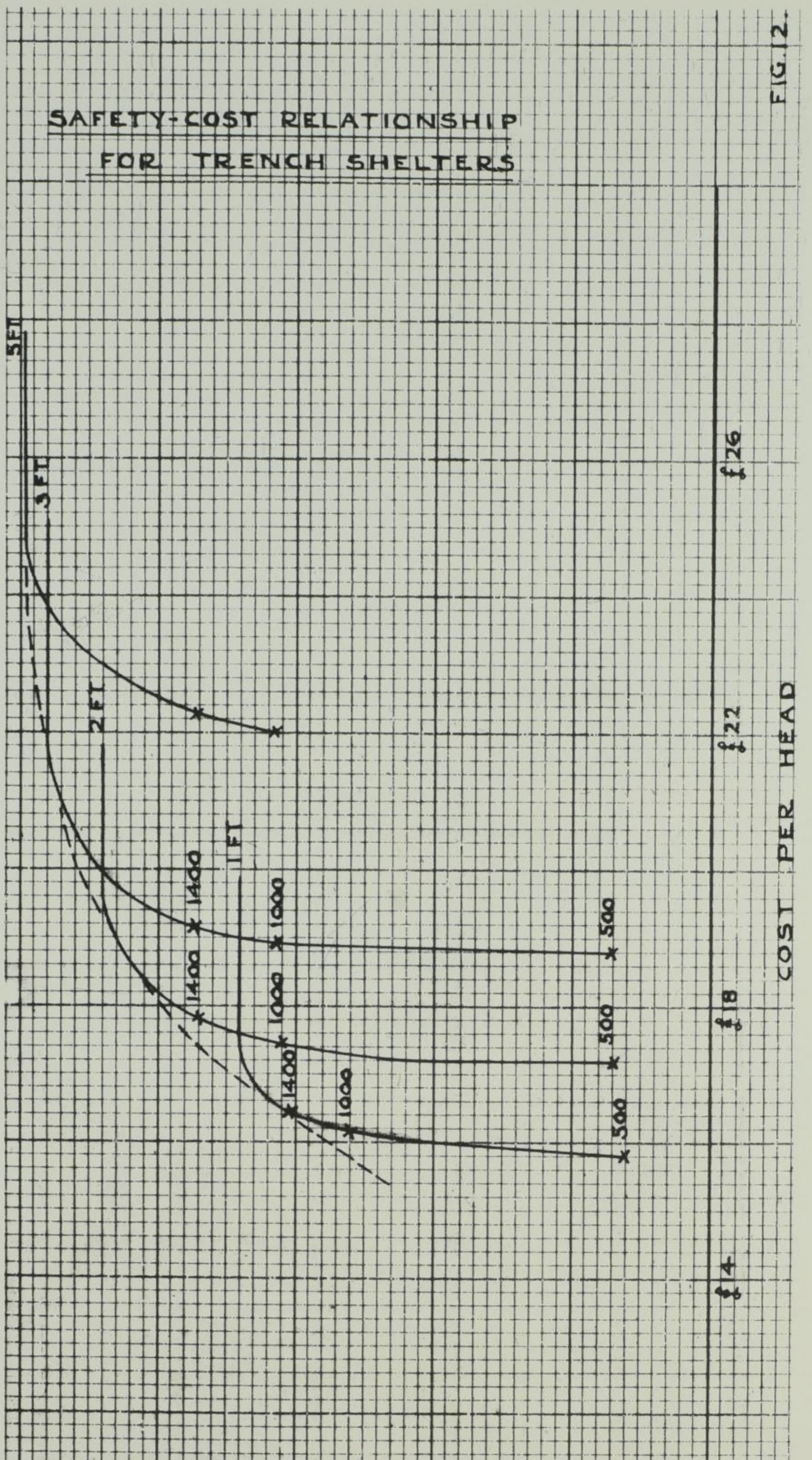


TRENCH SHELTERS.

FIG. 11.

(19908)

FIG. 12.



SAFETY-COST RELATIONSHIP FOR TRENCH SHELTERS

FIG. 12.

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HOME OFFICE

SCIENTIFIC ADVISER'S BRANCH

1st Draft

The Adaptation of Basement Garages under New Office Buildings for use as Shelters

by E. Leader-Williams

Introduction

1. At the present time the provision of car parking facilities on the site is a pre-requisite for planning permission for office blocks in the L.C.C. area and it is known that this also applies in Manchester and Liverpool. At least in the central part of the L.C.C. area, where sites are most valuable, the required parking facility is usually provided in the basement of the building, the basis being the provision of one parking space for every 2000 sq. ft. of office space.

It is understood that this garage space is at present being provided under new buildings in the L.C.C. area alone at the rate of 10,000 car spaces per year. This is equivalent to 250,000 shelter spaces per year on the last war basis of a space requirement for dormitory shelter of 10 sq. ft. per person. This space requirement may have to be increased somewhat for a long term occupancy, but it is used in this paper as a basis for cost calculations.

2. The plans of six new or proposed buildings in the West End have been examined and the following general observations apply -

(1) The sizes of the basement garages varied from 55,000 sq. ft. to 9,000 sq. ft. (i.e. 5,500 to 900 occupants on the basis of 10 sq. ft. per person).

(2) Two of the garages were in sub-basements with at least a basement, a ground floor and a roof over the whole garage. The remainder were in basements over portions of which the only cover was the ground floor slab. (In one case there was no cover at all over a small part of the basement garage space.)

(3) Access to the basement garages was normally by ramp, though in one case the car access was by lift. Where ramps were provided the normal

width was about 10 ft. which should permit of the entry of about 250 persons per minute. Use of both the in and out ramp would therefore allow an entry rate of about 500 persons per minute which should be adequate to fill most garage shelters in the assumed warning time of four minutes. Garages with lift access might have to be ruled out for shelter purposes unless they could be occupied in advance of the alert.

Blast protection

3. As they stand without alteration it is considered that basement garages under multi-storey steel or reinforced concrete framed office blocks would provide protection to their occupants from blast pressures up to about 10 p.s.i. (i.e. about four miles from a ground burst 10 Mt bomb). At this pressure the superstructure of the building would be very badly damaged, the panel walls would be blown in and the frame might be distorted, but the ground floor over the basement garage should not collapse. Moreover at this pressure it would not be essential to seal the shelter - American tests in Nevada suggest that the occupants of an unsealed shelter should not be injured at this pressure.

4. If the ground floor slabs over the basement garages were strengthened up to the old Grade A standard of strength but not of thickness (slab designed to carry a superimposed load of 1400 lb/sq. ft. at yield stresses) and the basement were sealed against the entry of blast by the provision of suitable blast doors etc. then it is estimated that the occupants should be safe against a blast pressure of at least 50 p.s.i. (i.e. 2 miles from a ground burst 10 Mt. bomb).

5. On the basis of the above estimates of strength, the relative blast casualties among a population in houses, in unstrengthened basements and in basements strengthened to grade A standard would be in the ratio of 1000 to 600 to 150.

6. It has been estimated (CDJPS(S)(54)5) that the extra cost of providing Grade A protection in the basement of an office building is about

5% of the cost of the building. Modern office buildings cost about 10/- per cubic ft. of space or say £5 per sq. ft. of floor area. The L.C.C. requirement for one car space per 2000 ft. of floor space therefore means that one car space would be provided from each £10,000 worth of building. One car space (250 sq. ft.) equals 25 shelter spaces at 10 sq. ft. per person, so that 25 shelter spaces would be provided for each £10,000 worth of building. If the provision of Grade A requirements costs 5% of the cost of the building, the structural provision for each shelter space would therefore cost £20.

Fall-out Protection

7. The two sub-basement garages referred to in paragraph 2 would have a protective factor exceeding 1000 over their whole area. The remaining basements would have a protective factor of more than 1000 over most of their area, but those portions which only had a ground floor slab overhead would be unlikely to have a protective factor exceeding 50. This wide discrepancy is clearly most undesirable in a fall-out refuge. One method of overcoming it, which is being advocated by the U.S. Authorities in the surveys of potential fall-out refuge which they are undertaking, would be by lines painted on the floor to indicate to the occupants which portions of the garage should, and which should not, be used as refuge. Alternatively walls could be constructed to shut off those portions of the basement not suitable for shelter though this could probably not be done without interfering with the peace time use of the garage.

8. If it is required to achieve a protective factor of 200 over the whole basement the ground floor slab would have to be thickened over those portions where it formed the only cover over the basement. For this a slab thickness of about 15 inches would be required to give a protective factor of 200 and the extra cost of this, as compared with the normal slab of about 6 inches thickness, should not exceed about 7/6d. per sq. ft. or say £4 per shelter occupant of those areas where roof thickening is required or £6 per occupant for P.F. of 1000.

9. The provision of a 50 p.s.i. (Grade A) slab over the basement would ensure a protective factor of at least 200 over the whole basement.

Protection from other Hazards

10. Fire. It is not considered likely that a fire storm, such as the one which caused so many casualties among the occupants of basement shelters in Hamburg, would result from a nuclear attack on a British city. Individual buildings, and whole blocks, would certainly be destroyed but modern office buildings of the type under consideration would be among the least likely to be involved. If the basement shelters are designed for 50 p.s.i. they will have to be sealed against the entry of blast and should therefore provide complete protection from fire even if the building over and the surrounding buildings are engulfed in a conflagration. If they are designed for 10 p.s.i. and are therefore not sealed there would be some fire hazard to the occupants, but it would be small and they might have time to seek alternative accommodation if their building appeared likely to be engulfed.

11. Flooding. Basements in low-lying parts of London would be in danger of flooding from a ground burst bomb which breached the Thames. However the crater would take some time to fill and the occupants should have plenty of time to leave before the floods threatened them. Damage to the building over the shelter, with consequent breakage of water mains, might pose a slow flooding risk. However there were few records of this type of incident in the last war and it is considered that the risk is trivial in comparison with the risks of blast and fall-out.

Ventilation

12. The normal* L.C.C. requirements for the ventilation of basement and sub-basement garages are that natural ventilation should be sufficient to provide for three air changes per hour and in addition mechanical ventilation

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*In exceptional cases, where natural ventilation cannot be provided, an additional mechanised plant, capable of providing three air changes per hour, must be provided and must be capable of running should a failure occur in the principal source of power supply.

independent of any ventilating plant for other parts of the building should be provided sufficient to give three air changes per hour. The openings (amounting to not less than 2½% of the area of the floor of the garage) required for natural ventilation are normally provided by the ramp entrances to the garage, which are closed by gates of the lattice type to permit a free flow of air.

13. If the garage were used as an unsealed 10 p.s.i. shelter (see para.3) then it is considered that natural ventilation (where provided) will be adequate. Moreover the air speeds involved in this natural ventilation are so low that there is little risk of dangerous fall-out particles being carried into the shelter by the ventilating air. Where natural ventilation is not provided, the requirement for a second means of ventilation, independent of the main source of supply, should ensure adequate ventilation if the garage is used as a shelter.

14. It therefore appears that only if the garage is naturally ventilated but is intended for use as a sealed 50 p.s.i. shelter (see para. 4) will there be any requirement for additional ventilation equipment. It is estimated that stand-by generators to provide the necessary power for this and for a degree of lighting would cost about £5 per shelter space.

Standard of Shelter to be adopted

15. The alternatives appear to be either to use the buildings virtually as they are as 10 p.s.i. shelters or to strengthen the ground floor slabs to provide Grade A (50 p.s.i.) shelters.

16. If the former course is adopted the only structural alteration worth consideration would be the thickening of unprotected parts of the ground floor slab to provide a protective factor of 200. The cost of this would be unlikely to exceed an average of £1 per shelter space (assuming that an average of 75% of basement garage space had a building over it and not just a ground floor slab). On the whole this is not considered to be

worthwhile expenditure. It would add nothing to the blast resistance of the shelter and the same effect as far as fall-out is concerned could be achieved, without cost, by excluding the use as shelter of inadequately protected parts of the basement.

17. The existing provisions for ventilation should be satisfactory for 10 p.s.i. shelters, and the only provisions which would have to be made in peacetime would therefore be the provision of standby generating plant for lighting purposes and the provision of water storeage for the shelter occupants. These are comparatively trivial provisions which could do little to promote public confidence in the buildings as shelters and there would seem to be little justification for making them at the present time. If nothing is done we shall still be accumulating potentially useful shelter space at the rate of about 200,000 shelter spaces per year in the L.C.C. area alone, and the provision of standby generating capacity and water storage could well be left till war seems more imminent.

18. The strengthening of the ground floor slabs to 50 p.s.i. (Grade A) would cost about £20 per shelter space and, since the shelters would be sealed, provision would also have to be made for standby generating equipment to work the ventilation system in event of power failure. The cost of this and the other measures required (e.g. water storage) should not exceed £5 per shelter space, so that the total cost of providing really first class shelter would be about £25 per head. If this were applied to all the new buildings in the L.C.C. area alone it would entail an annual cost of about £6 million.

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UNITED KINGDOM ATOMIC ENERGY AUTHORITY

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT No. T 47/57

BB005

OPERATION BUFFALO

Target Response Tests
(Co-ordinator : E. R. Drake Seager)

The Effect of Earth Covers on the Resistance of Trench Shelter Roofs

A. J. Wood

A.W.R.E.,
Aldermaston, Berks.

[redacted]

August, 1957

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[redacted]

United Kingdom Atomic Energy Authority

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT NO. T47/57

OPERATION BUFFALO

The Effect of Earth Covers on the Resistance of Trench Shelter Roofs

A. J. Wood

Summary

This report describes the effect of an atomic weapon of about 20 kilotons total energy yield on full-size and model trench shelter roof panels with varying amounts of earth cover. Static tests on both scales were also carried out, and details of all results obtained are given.

Received on 22nd July, 1957

Table of Contents

1. Introduction

To obtain information on the effect of earth cover on the resistance to blast of trench shelter roof slabs a series of targets was exposed to Round 1 of Operation Buffalo, which had a total energy yield of about 20 kilotons. These targets were both full-scale and model scale. The model targets were 1/10th full-size, and were included to provide information on the effects of a Megaton weapon.

The slabs were designed by the Ministry of Works [Refs. 1 and 2], the overall dimensions of the full-scale panels being 21 ft x 8 ft x 6 in., and of the 1/10th scale panels 25 in. x 9.4 in. x 0.6 in. The discrepancy between the full-size and model dimensions was caused by differences in the widths of the bearing surfaces; for the full-size slabs this surface was 6 in. all round, giving a clear span of 20 ft x 7 ft, whereas the model slabs were supported on bearing surfaces only 0.5 in. wide, giving a free span of 24 in. x 8.4 in. The corners of the slabs were held down (with reinforcing rods and concrete on the full-size slabs, and special steel clamps on the model slabs) for a length equal to 1/10th of the free span in each direction.

Eight full-size slabs were to be cast, six to be placed in the field, the remainder to be tested statically. Of the six in the field three were at ground level and the other three were buried to give 5 ft of earth cover. Forty-eight models were cast, 36 of which were exposed in the field, 9 models being buried 12 in. below ground level, 9 buried 6 in. deep, 9 buried 3 in. deep and 9 placed level with the surface of the ground.

2. Object of the Investigation

2.1 Full-Size Slabs

The main purpose of this test was to study the effect of earth cover upon the resistance of a reinforced concrete slab to blast loading from a kiloton weapon, and to determine whether static tests could be used to predict performance under blast loading.

2.2 Model Slabs

Again an important part of this test was to study the effect of earth cover on the resistance of the slabs to blast loading from a kiloton weapon and to obtain an assessment of the effect of Megaton weapons on such structures. In addition the experiment was designed to show whether results from static tests could be used to predict the blast resisting performance of this type of structure.

3. Description and Construction of Panels

3.1 Full-Scale

The full-scale panels were rectangular, the dimensions being 21 ft × 8 ft × 6 in. overall. The reinforcement, which was in the bottom face only, consisted of 60 bars $\frac{3}{8}$ in. in diameter at $4\frac{1}{4}$ in. centres across the short span. This gives a percentage reinforcement of 0.431. The only longitudinal steel consisted of 5 bars $\frac{3}{8}$ in. in diameter at 18 in. centres, to act as distribution steel. All reinforcement complied with British Standard Specification No. 785 for mild steel. The concrete cover for the reinforcement was 1 in. This was kept constant by the use of annular bar-spacers.

As can be seen from Figure 1, the thickness of the panel was reduced to 4 in. at the corners, and also the sides were recessed 2 in. This can be seen more clearly in Figure 2 and Figure 3, and was to allow the anchoring bars to be concreted into position. Figure 3 also shows these bars bent over into position, and Figure 4 shows a corner that has been completed.

Again from Figure 1 it can be seen that 20 lifting bars were included in the panel, 10 each side of the centre line, along the span. These lifting bars were $\frac{5}{8}$ in. diameter at 2 ft $1\frac{1}{2}$ in. centres. The distance of the centre line of the bars from that of the panel was 2 ft 3 in.

The concrete mix from which the panels were made was designed to give a compressive strength of 3000 p.s.i. at the time of firing. The mix was in the proportions of 1 part Normal Portland cement (Australian type A, complying with B.S.S. 12) to $3\frac{1}{2}$ parts of coarse aggregate (approximating to $\frac{3}{4}$ in. aggregate, B.S.S. 882) to $3\frac{1}{2}$ parts of fine aggregate (zone 2 crushed stone sand, B.S.S. 882), with a water/cement ratio of 0.875. The materials and design of mix are described in detail in Ref. [3], and grading curves for the aggregates are shown in Figure 5.

The panels were cast in wooden moulds, the base of the mould being lined with building paper and the sides well greased. This wooden mould was placed on a flat concrete slab. The intention initially had been to cast direct on to the concrete slab using only building paper as the base. However, it was found that with the paper alone the adhesion was high, and it was necessary to introduce the wooden base. The reinforcing mat was made up outside the mould, and placed in position just before casting.

Mixing was carried out using a weigh-batching machine and a 10/7 freefall mixer. Compaction was effected with a high frequency poker vibrator. From every second mix, two 6 in. control cubes were cast, and in addition, from every fourth mix a 4 in. × 4 in. × 36 in. control beam was made. Each panel needed about 16 mixes to fill it, and the position of each mix was noted as it was placed (Figure 6). As the strength of the concrete at the time of firing (estimated at 10 to 14 weeks after casting) was to be only 3000 p.s.i. the concrete was of very low strength for some time after it had been cast. The panels were therefore allowed to harden for as long as possible before being moved to the storage area. However, this time was a maximum of 7 days, and it was necessary to add support longitudinally before lifting the panel as there was very little longitudinal reinforcing actually in the panel. Therefore two 12 in. × 6 in. R.S.J.'s were tied to the panel, using $\frac{1}{4}$ in. diameter steel wire rope, by means of the lifting bars which had been cast into the panel. Two lifting eyes were bolted to each of the R.S.J.'s and the panel was then lifted using chain brothers. The arrangement for tying down the R.S.J.'s and positions of the lifting eyes can be seen in Figure 1.

3.2 Model Scale

The dimensions of the 1/10th scale model panels were 25 in. × 9.4 in. × 0.6 in. The reinforcement across the span consisted of 63 wires 0.036 in. in diameter (20 S.W.G.) at 0.4 in. centres, on the bottom face only. This gave a percentage reinforcement of 0.428. The only reinforcement along the span was distribution steel consisting of 6 wires of 20 S.W.G. at 1.66 in. centres. The cover on the reinforcement was 0.1 in. Details of the slab can be seen in Figure 7.

The panels were cast with a mortar, the "sand" being crushed limestone. All the sand was graded on a vibrating screen, that portion retained on a B.S. No. 100 mesh and passing a B.S. No. 7 mesh being used. A mean grading curve can be seen in Figure 5. The proportions of the mix were 1 part Normal Portland cement (type A) to $4\frac{1}{2}$ parts of sand, with a water/cement ratio of 0.875. This mix, like that for the full-size panels, was designed to give a compressive strength of 3000 p.s.i. at the time of firing [Ref. 3]. The mix was weighed in a laboratory scale and mixed in a Cumflow pan-type mixer of $1\frac{1}{4}$ ft^3 capacity.

The panels were cast in wooden moulds (Figure 8) in batches of six, a total of eight batches being cast. With each batch of six, which was made from one mix, one control beam 4 in. × 4 in. × 36 in. and three 4 in. cubes were cast from the same mix. Both the panels and controls were compacted on a vibrating table.

The panels were allowed to harden for about 48 hours before being demoulded, and immediately after demoulding were immersed in water for curing. Curing was continued for about 8 weeks. Before the panels were placed in the field they were thoroughly washed with fresh water (salt water having been used for curing) and the undersides whitewashed. This was done so that any fine cracks caused by the blast could be photographed more easily.

4. Field Placing

The slabs were positioned in the field from information obtained in the United Kingdom [Ref. 4].

4.1 Full-Size Slabs

Eight full-size slabs were cast. They were supported on a strip 6 in. wide along each edge. The support was made up of reinforced concrete beams resting on top of mass concrete retaining walls. The dimensions of the beams and walls were such that there was a cavity at least 3 ft deep beneath the panel. The whole arrangement can be seen in Figure 1. To ensure that the slabs were in fact bearing evenly along each edge a layer of soft mortar was placed along the supporting surfaces before the panel was placed in position. So that the panel did not key in any way to the supports, a strip of greased building paper was placed on the bearing surfaces. The panel was positioned and the corners of the panel were then tied down to the supports by means of anchor bars. These anchor bars (½ in. in diameter) had been grouted into the supports before the panel was placed in position. When the panel had been placed, they were bent over the corners into the portion of the panel which had been specially recessed (Figure 3), and then the recess was filled with mortar to the level of the panel (Figure 4). When the bedding mortar had hardened, the ½ in. wide gap between the side of the panel and the supporting beam was filled with a bituminous sealing compound. This gave an airtight plastic joint all round the panel.

Three of the panels exposed were level with the surface of the ground and were subjected to maximum pressures of 21.6, 14.5 and 10.3 p.s.i. Figure 9 shows a panel in position. Three further panels were exposed at 27, 17.9 and 12 p.s.i., these being 5 ft below ground level and covered with earth to ground level. The damage expected at these ranges was heavy, moderate and light respectively. At the higher pressure levels the blast wave was not of the usual sharp-fronted type and the pressures given are the maximum values recorded.

Unfortunately, the panels with earth cover were all cracked slightly during handling. The worst of these, at 27 p.s.i., was cracked all across the short span. The other two panels had short cracks in this span.

The deflections of the panels in the surface were measured with a levelling staff and level. Nine positions on the surface were selected, and their levels relative to a fixed position on the curb beam found. This was carried out before and after firing, and thus the deflection caused by the blast calculated. It was assumed that the point on the curb beam did not move. To have attempted to make an absolute measure of the deflection, using a bench mark out of reach of air or ground shock, would have been unnecessary and impracticable.

The deflections of the panels with earth cover were measured from underneath using a builder's level, a rigid datum and a scale. This arrangement can be seen in Figure 10. The datum was rested on the mass concrete walls, and levelled using the builder's level. The measurements were then recorded using a flexible steel rule. The points at which measurements were taken coincided as nearly as possible with those positions at which levels were taken on top of the panel before firing (9 points in all), and together with the measurements against the curb beam made a total of 15 measurements (see Figure 10). From these measurements the deflections of the slabs were calculated.

4.2 Model Slabs

The panels were placed on steel box supports, the boxes being made of $\frac{1}{2}$ in. steel plate. The inside dimensions of the boxes were 24 in. × 8.4 in. × 8.4 in. deep. The $\frac{1}{2}$ in. wide supporting surfaces, formed by the sides of the box, were machined flat. So that the corner clamps could be secured, 2 in. × $1\frac{1}{2}$ in. × 3/16 in. angle-iron was bolted round the top of the box. A sketch of the box can be seen in Figure 11. To simulate the corner conditions of the full-size slab, the corners of the model were clamped down with a special clamp which, like the full-size corner condition, restrained the panel for 1/10th of the span. A detail of the clamp also appears in Figure 11. To avoid clamping the panel down so tightly that high stresses were induced, the bolts on the clamps were all only finger-tight.

Unfortunately, owing to a fault which developed in the mould, the panels were all hogging, and therefore to ensure that the panels were supported all along their edges a mix of approximately equal quantities of cement and dune sand, with enough water to give a very workable mix, was placed along the supporting surfaces of the steel boxes. The panel was then placed into position and pressed down firmly. The clamps were fitted and tightened immediately. It was assumed that the whitewash on the panels would prevent bonding between the box and the slabs by the new mortar.

The model panels were all similar but had varying amounts of earth cover. These amounts were specified as 3 in., 6 in. and 12 in. A series was also exposed without cover. Figure 12 shows a panel in the surface ready for firing. The table below details the maximum pressures at which the panels were exposed and the amount of earth cover, together with the amount of damage expected.

Depth of Earth Cover, in.	No. of Models at Each Distance				
	1	2	3	2	1
	Pressure, p.s.i.				
0	8.0	10.3	13.2	17.9	21.6
3	9.0	11.1	14.5	17.9	23.8
6	10.3	13.2	17.9	21.6	27.0
12	12.0	17.9	21.6	27.0	33.5
Damage Expected	None	Light	Moderate	Heavy	Destroyed

The deflection measurement was made with a rigid "bridge" measuring device, incorporating a dial gauge graduated in 0.001 in. to read up to 2½ in. A reading was taken before and after firing, and the deflection calculated. The measuring device was checked before and after firing on a surface plate. The 1, 2, 3, 2, 1, distribution was adopted to economize on the number of panels exposed. The distribution was weighted in this way to give the greatest number of panels at the distance where moderate damage was expected.

A damage analysis from sketches and photographs of crack patterns was required, together with a measure of the residual central deflection. The residual central deflection was required as in this type of panel it was often the only real indication that damage had occurred.

5. Static Tests

5.1 Full-Scale

Two full-scale panels were to have been tested statically, but when lifting one of the panels soon after casting, the crane was not powerful enough to be able to slew the panel on to the transport vehicle, and when the panel was put on the ground it broke into two pieces. This panel could not be replaced, and thus only one was tested.

The panel was set up in a heavy R.S.J. reaction frame, supported on a frame made up of R.S.J.'s. Load was applied through 16 hydraulic jacks and a beam load-spreading system, terminating in 128 wooden feet 2 in. in diameter. The rig and supporting frame is shown in Figure 13. As in the field, a layer of soft mortar was placed on the supporting surfaces before the panel was placed in position, and a strip of greased paper separated the supporting from the bearing surfaces.

During the test, simultaneous readings of load, time and central deflection were taken, this latter being measured with a dial gauge graduated in 0.001 in. to read up to 12 in. Photographs were taken of the development of the crack pattern during the test.

The 6 in. control cubes were crushed to give the compressive strength of the concrete in each panel. The modulus of rupture was derived by applying the theory of simple bending to the results obtained by loading the beam to failure under a two-point loading system in an Avery Universal testing machine.

5.2 Model Scale

The machine used for statically testing the control panels was a Macklow-Smith 200-ton compression testing machine, fitted with a special 20-ton poise, enabling a load of 0.001 tons to be recorded. As in the full-size test, the load was applied to the panel through a beam load-spreading system, terminating this time, however, in 32 wooden loading blocks each 1 in. in diameter. The central deflection of the panel was measured with a dial gauge of 1 in. travel, graduated in 0.001 in. divisions. Simultaneous readings of load, deflection and time were taken throughout the test.

The panel was supported on an angle-iron frame, designed so that the panel was supported on a ½ in. wide strip all round the edges, and the corners were restrained with clamps identical to those used in the field. The whole arrangement ready for testing can be seen in Figure 14. Also, to simulate the field conditions and to ensure all-round support, the panel was bedded on to the frame with a sand-cement grout, as described in Section 4.2.

As has been stated earlier, the panels were cast in eight batches of six. From seven of these batches, five from each batch were tested in the field, the remaining one being statically tested in the laboratory. From the eighth batch only one panel was needed in the field to make a total of 36. One from this batch was tested statically, giving a surplus of 4 panels.

As some of the full-size panels had been cracked before firing, it was decided to crack these surplus models in the same way as the full-size panels were cracked, but rather more severely, and to carry out static tests. From the results it was seen that there was no appreciable difference in strength between the cracked and uncracked panels.

The compressive strength of the mortar was measured by crushing the 4-in. cubes, and the modulus of rupture was obtained from the beams in the same manner as for the concrete of full-size panels. The ultimate tensile strength of the reinforcing wire was checked by making tests with a Hounsfield Tensometer on samples of wire taken from the panels after static and blast loading tests had been carried out. These wires were very rusty, owing to the action of the salt water used in making the mortar. The results were calculated from the nominal diameter of the wire before casting, and not from the actual diameter of the wire after rusting.

6. Results

The results are shown in Tables 1 and 2. Owing to the fact that the blast wave at the nearer distances was not of the usual sharp-fronted form, the pressures quoted throughout this report are the maximum pressures reached. Figure 15 shows the load/deflection curve for the full-size panel tested statically, and Figure 16 the mean static load/deflection curve for the model panels. Figure 17 shows the load/deflection characteristics of model panels cracked before testing. Figures 18-22 show photographs of damage to full- and model scale panels. Figure 6 details the positions in which the different batches were added in the full-size panels, together with the mean value of the compressive strengths of those mixes from which control cubes were made. Figures 23 and 24 show sketches of the crack patterns of the full-size slabs after firing, and Figures 25 and 26 photographs of typical failures on full- and model scale statically tested panels.

7. Comment on Results

7.1 Effect of Earth Cover on Full-Size Slabs

The effect of the earth cover on the full-scale slabs can be seen in Table 1. It will be noticed that whereas a panel at about 22 p.s.i. with no cover was destroyed, that at 27 p.s.i. with 5 ft of earth cover, whilst being heavily damaged, was not destroyed. From this example it would seem that the earth cover had a considerable effect. However, the panel at $14\frac{1}{2}$ p.s.i. with no cover had a residual central deflection only very slightly greater than that with earth cover at 10 p.s.i. and less than half the deflection of the panel with cover at 18 p.s.i. These points would indicate that the cover had a greater effect at the higher pressures. It will be seen from Table 1 that the mean compressive strength of the statically tested panel was only about 2000 p.s.i. as compared with a value for the field tested panels of 3000 p.s.i. In information not yet published it has been shown that an increase of strength of this order on a 12 in. square unreinforced panel 1 in. thick gives an increase of static strength of about $1\frac{1}{2}$ p.s.i. It is considered that the increase in strength on a full-scale trench shelter roof panel would be of the same order.

7.2 Effect of Earth Cover on Model Panels

Table 2 shows that all panels were destroyed at pressures greater than 22 p.s.i. At 18 p.s.i. the only panels to survive were those with 6 in. of earth cover, and these were very near to collapse. Those panels with 3 in. of cover exposed at 14.5 p.s.i. survived, as did all panels exposed to pressures equal to or less than 13 p.s.i.

The damage sustained by these model slabs is comparable with that which full-scale slabs should experience at the same pressure level from a weapon in the kiloton range. The abnormal shape of the blast wave at the nearer distances will have a small but not outstanding effect.

The figures given for the final central deflection are not necessarily a reliable guide to the maximum deflection [Ref. 5], but are included as the only real indication that the panels suffered any damage at all since only four of the surviving panels were visibily cracked, and as can be seen from the photographs in Figures 9-22 the cracking even in these cases was very light.

8. Conclusions

The test showed that the earth cover on the full-size slabs did in fact have the effect of reducing damage, while on the model scale, although the effect was not so marked, it was apparent. The range of damage sustained was, on the whole, satisfactory for both the model and full-scale, which, since the ranges for both types were predicted from model static and blast tests, indicates that this is an acceptable method for predicting performance under blast loading.

References

1. Ministry of Works Drawing No. Q/1036B.

2. Ministry of Works Drawing No. Q/546B.

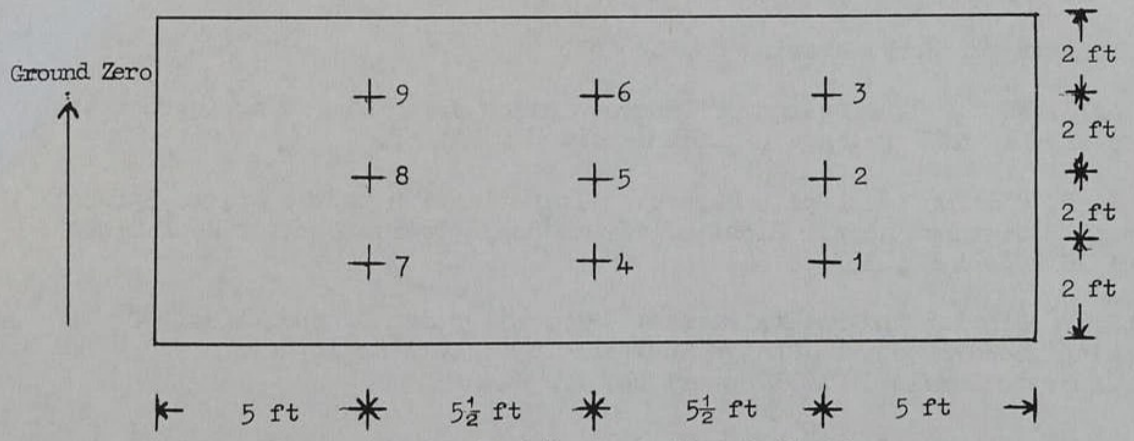
3. A. J. Wood: "The Design of Concrete Mixes Using Limestone Aggregates Available at Maralinga". AWRE Report No. T35/57.

4. T. P. O'Brien and Pepita Pirrie: "Investigation of the Static Strength and Resistance to Air Blast of 1/10th Scale Trench Shelter Roof Slabs". AWRE Report No. E5/57.

5. T. P. O'Brien and Pepita Pirrie: "Investigation of the Effect of Blast Loading on the Damage Sustained by 1/10th Scale Reinforced Concrete Panels". AWRE Report No. E8/56.

TABLE 1

Details of Damage to Full-Size Panels



Plans of Slab: Positions at which Deflections were recorded Shown: +

Panel No.	Maximum Pressure, p.s.i.	Deflection (in.) at Position									Control Cube Strength, p.s.i.	Modulus of Rupture, p.s.i.
		1	2	3	4	5	6	7	8	9		
Panels with No Cover												
2A/A/4	21.6				Destroyed						3230	430
2A/A/6	14.5	0.4	0.7	0.4	0.5	0.9	0.5	0.3	0.6	0.4	3510	449
2A/A/8	10.3	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	2750	347
Panels with 5 ft Earth Cover												
2A/A/2	27.0	0.7	3.5	1.7	2.0	4.1	1.9	1.9	3.4	1.7	3340	346
2A/A/5	17.9	0.8	1.3	0.5	1.0	2.1	0.7	0.7	1.6	0.6	2969	360
2A/A/7	12.0	0.3	0.4	-0.1	0.4	0.8	0.2	0.4	0.7	0.3	2234	320

Panel No. 2A/A/3 was tested statically:

Max. load = 14.61 p.s.i.
Central defl. at max. load = 1.85 in.
Control cube strength = 2140 p.s.i.
Modulus of rupture = 257 p.s.i.

TABLE 2

Details of Damage to Model Panels

Panel No.	Maximum Pressure, p.s.i.	Final Central Deflection, in.	Control Panel Characteristics			
			Cube Strength, p.s.i.	Modulus of Rupture, p.s.i.	Max. Static Pressure, p.s.i.	Deflection at Max. Load in.
Panels with No Cover						
2B/B/2	21.6	Destroyed	3330	651	8.56	0.060
2B/A/2)	17.9	(Destroyed	3440	609	9.55	0.043
2B/B/4)		(Destroyed	3330	651	8.56	0.060
2B/D/1)	13.2	(0.076	3750	724	8.30	0.039
2B/C/1)		(0.062	3420	703	10.37	0.049
2B/D/2)		(0.057	3750	724	8.30	0.039
2B/D/5)	10.3	(0.057	3750	724	8.30	0.039
2B/E/5)		(0.056	3290	682	9.00	0.083
2B/F/1	8.0	0.048	3120	609	10.47	0.084
Panels with 3 in. Earth Cover						
2B/C/6	23.8	Destroyed	3420	703	10.37	0.049
2B/C/4)	17.9	(Destroyed	3420	703	10.37	0.049
2B/G/4)		(Destroyed	3230	661	11.14	0.079
2B/E/2)	14.5	(0.069	3290	682	9.00	0.083
2B/F/6)		(0.054	3120	609	10.47	0.084
2B/A/5)		(0.094	3440	609	9.55	0.043
2B/D/4)	11.1	(0.057	3750	724	8.30	0.039
2B/G/2)		(0.062	3230	661	11.14	0.079
2B/H/4	9.0	0.041	3490	598	10.38	0.122
Panels with 6 in. Earth Cover						
2B/E/1	27.0	Destroyed	3290	682	9.00	0.083
2B/D/6)	21.6	(Destroyed	3750	724	8.30	0.039
2B/C/5)		(Destroyed	3420	703	10.37	0.049
2B/C/2)	17.9	(0.127*	3420	703	10.37	0.049
2B/G/1)		(Destroyed	3230	661	11.14	0.079
2B/B/1)		(0.184*	3330	651	8.56	0.060
2B/A/6)	13.2	(0.042	3440	609	9.55	0.043
2B/F/4)		(0.053*	3120	609	10.47	0.084
2B/B/6	10.3	0.040	3330	651	8.56	0.060
Panels with 12 in. Earth Cover						
2B/A/4	33.5	Destroyed	3440	609	9.55	0.043
2B/G/5)	27.0	(Destroyed	3230	661	11.14	0.079
2B/E/4)		(Destroyed	3290	682	9.00	0.083
2B/B/5)	21.6	(Destroyed	3330	651	8.56	0.060
2B/E/6)		(Destroyed	3290	682	9.00	0.083
2B/F/5)		(Destroyed	3120	609	10.47	0.084
2B/A/1)	17.9	(Destroyed	3440	609	9.55	0.043
2B/F/2)		(Destroyed	3120	609	10.47	0.084
2B/G/6	12.0	0.068*	3230	661	11.14	0.079

*Visible cracking

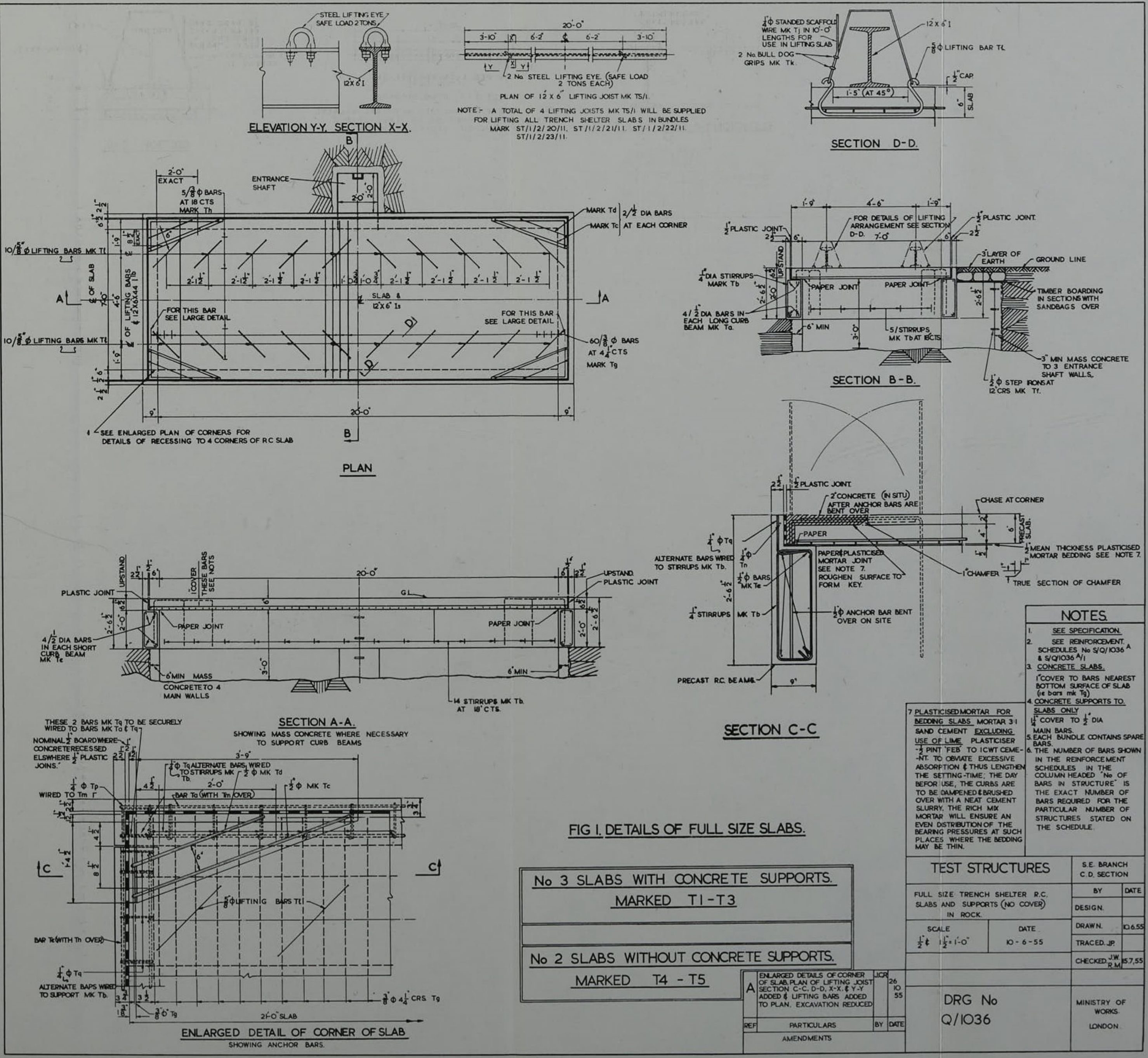


FIG I. DETAILS OF FULL SIZE SLABS.

No 3 SLABS WITH CONCRETE SUPPORTS.
MARKED T1-T3

No 2 SLABS WITHOUT CONCRETE SUPPORTS.
MARKED T4 - T5

NOTES.

1. SEE SPECIFICATION.
2. SEE REINFORCEMENT. SCHEDULES No S/Q/1036 A & S/Q/1036 A/1
3. CONCRETE SLABS. 1" COVER TO BARS NEAREST BOTTOM SURFACE OF SLAB (ie bars mk Tg)
4. CONCRETE SUPPORTS TO. SLABS ONLY 1 1/4" COVER TO 1/2" DIA MAIN BARS.
5. EACH BUNDLE CONTAINS SPARE BARS.
6. THE NUMBER OF BARS SHOWN IN THE REINFORCEMENT SCHEDULES IN THE COLUMN HEADED "No OF BARS IN STRUCTURE" IS THE EXACT NUMBER OF BARS REQUIRED FOR THE PARTICULAR NUMBER OF STRUCTURES STATED ON THE SCHEDULE.
7. PLASTICISED MORTAR FOR BEDDING SLABS MORTAR 3:1 SAND CEMENT EXCLUDING USE OF LIME. PLASTICISER - 1/2 PINT "FEB" TO 1CWT CEMENT. TO OBVIATE EXCESSIVE ABSORPTION & THUS LENGTHEN THE SETTING-TIME; THE DAY BEFOR USE, THE CURBS ARE TO BE DAMPENED & BRUSHED OVER WITH A NEAT CEMENT SLURRY. THE RICH MIX MORTAR WILL ENSURE AN EVEN DISTRIBUTION OF THE BEARING PRESSURES AT SUCH PLACES WHERE THE BEDDING MAY BE THIN.

REF	PARTICULARS	BY	DATE
A	ENLARGED DETAILS OF CORNER OF SLAB, PLAN OF LIFTING JOIST SECTION C-C, D-D, X-X. & Y-Y ADDED & LIFTING BARS ADDED TO PLAN. EXCAVATION REDUCED	JCR	26 10 55

AMENDMENTS

TEST STRUCTURES

S.E. BRANCH
C.D. SECTION

FULL SIZE TRENCH SHELTER R.C.
SLABS AND SUPPORTS (NO COVER)
IN ROCK.

SCALE 1/2" & 1 1/2" = 1'-0"
DATE 10 - 6 - 55

	BY	DATE
DESIGN.		
DRAWN.		10.6.55
TRACED.	JP	
CHECKED.	J.W. R.M.	15.7.55

DRG No
Q/1036

MINISTRY OF
WORKS.
LONDON.

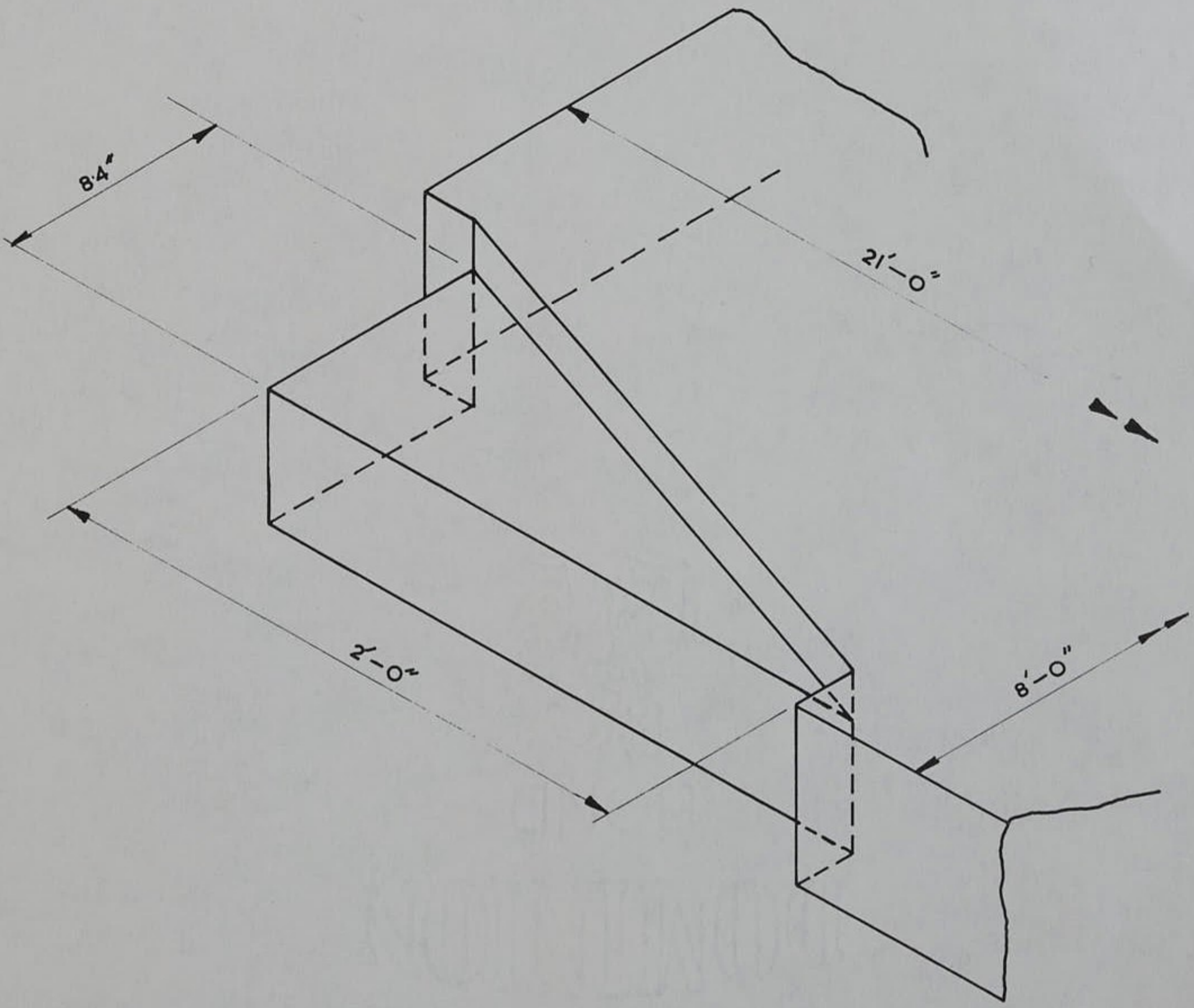


FIG. 2, CORNER DETAIL FULL SIZE SLAB.

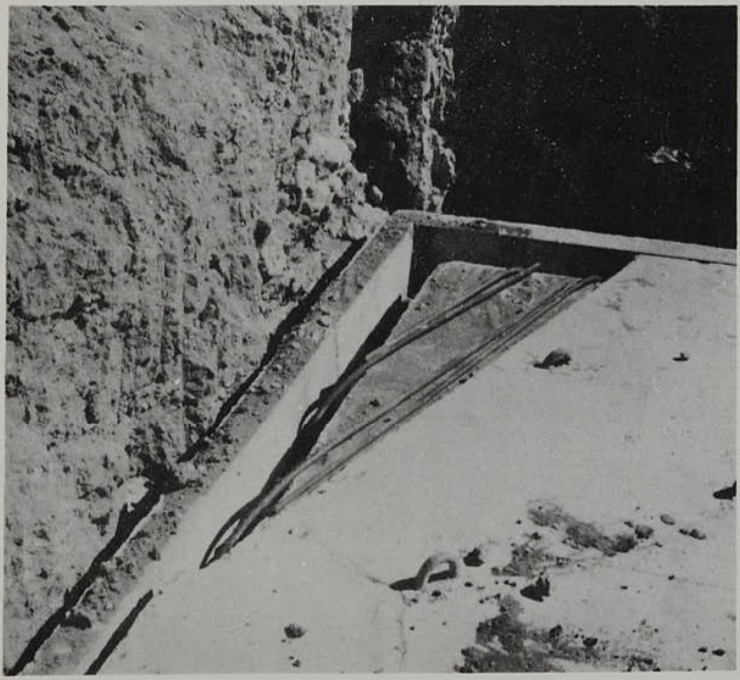


FIG. 3. DETAIL OF CORNER OF FULL SIZE SLAB SHOWING ANCHORING BARS BENT IN POSITION.

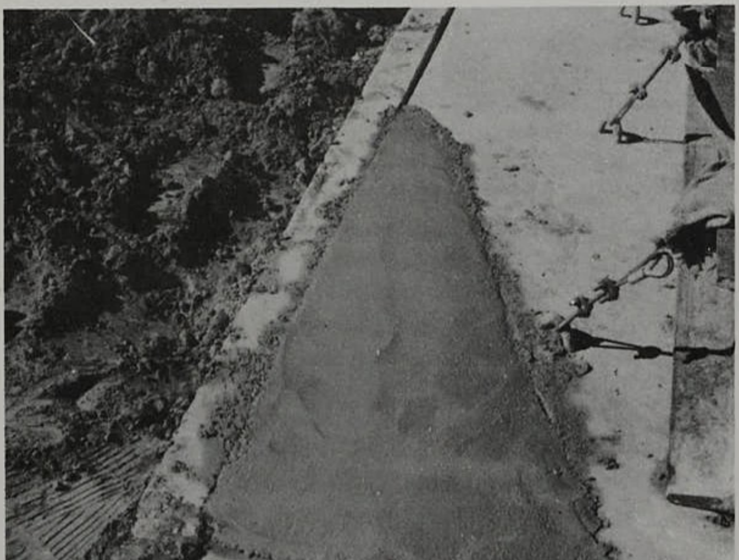


FIG. 4. COMPLETED CORNER FULL SIZE PANEL

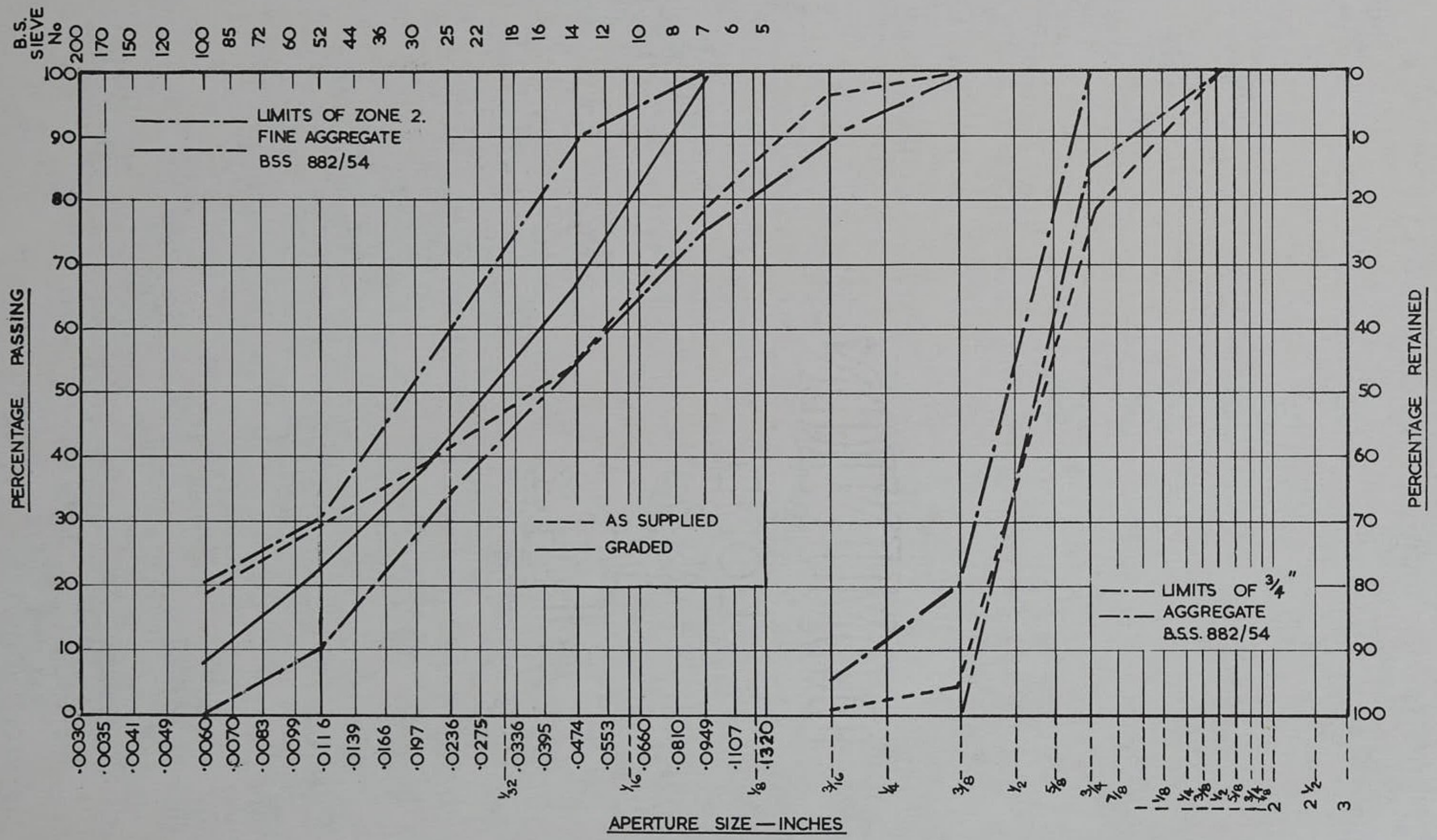
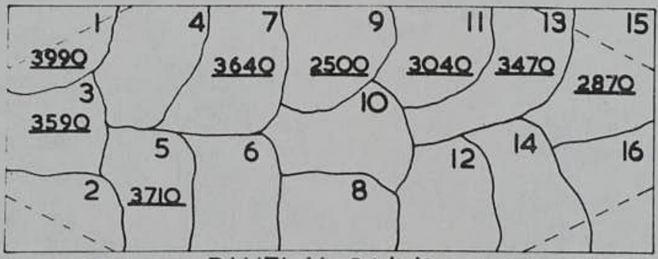


FIG. 5. GRADING OF AGGREGATE.



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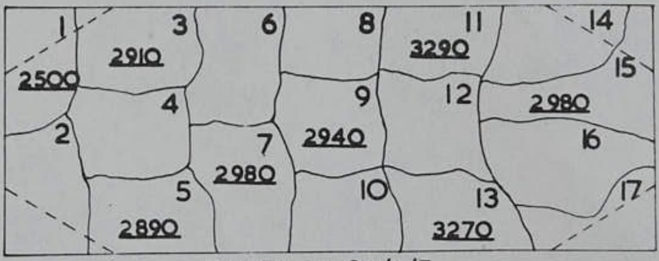
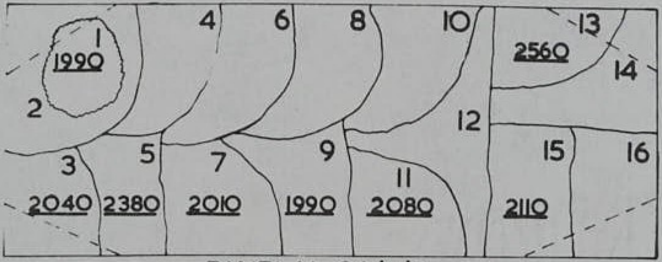


PANEL No 2A/A/5



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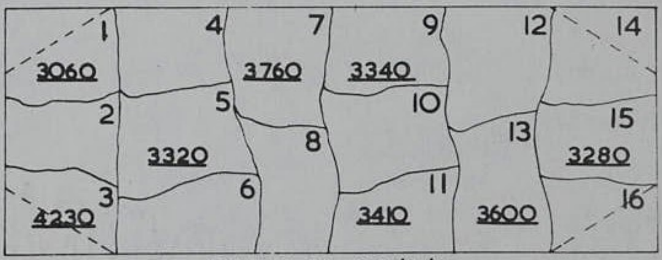
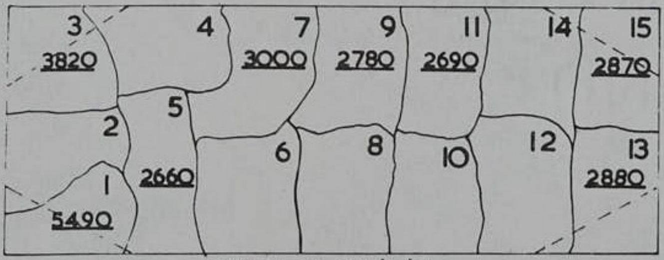
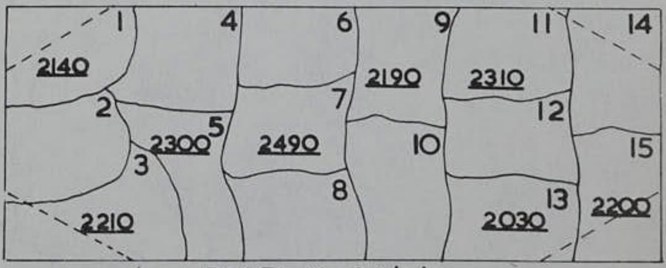


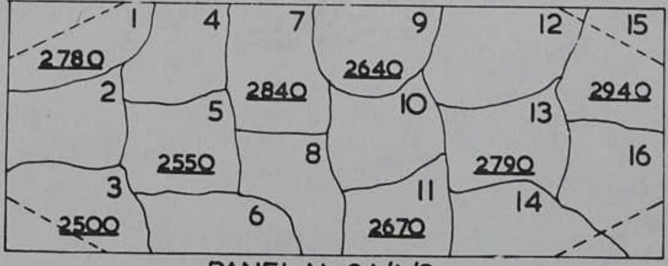
PANEL No 2A/A/6



PANEL No 2A/A/4



PANEL No 2A/A/7



PANEL No 2A/A/8

FIG.6. DIAGRAMS SHOWING POSITIONS OF MIXES IN PANELS. FIGURES UNDERLINED SHOW COMPRESSIVE STRENGTHS AS OBTAINED FROM CONTROL CUBES.

NOTES RE MATERIALS

AGGREGATES.

FINE AGGREGATES SHALL COMPLY WITH THE REQUIREMENTS OF BRITISH STANDARD 882 THE MAXIMUM SIZE OF AGGREGATE SHALL BE THAT PASSING A 1/16" BRITISH STANDARD SIEVE.

CEMENT.

THE CEMENT SHALL BE PORTLAND CEMENT AND SHALL COMPLY WITH THE REQUIREMENTS OF BRITISH STANDARD 12.

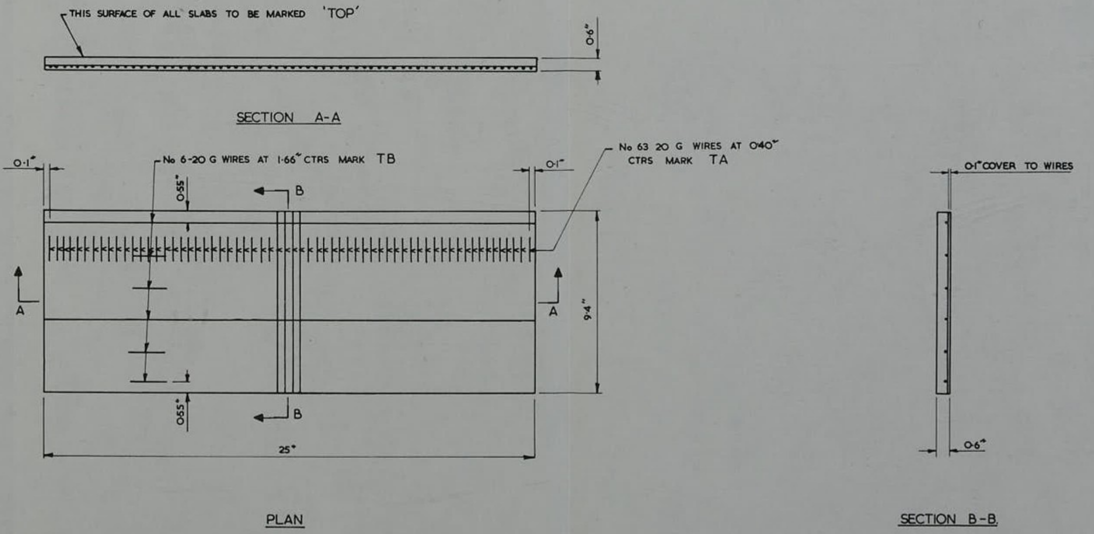
REINFORCEMENT.

THE REINFORCEMENT SHALL BE MILD STEEL TO COMPLY WITH THE REQUIREMENTS OF BRITISH STANDARD 785. THIS MAY BE OBTAINED BY ANNEALING HIGH TENSILE WIRE PROVIDED THAT THE ULTIMATE STRESS AND ELONGATION IS AS DEFINED IN APPENDIX 'A' OF BRITISH STANDARD 785 FOR MILD STEEL.

REINFORCED CONCRETE.

CONCRETE MIX.

THE CONCRETE IS REQUIRED TO HAVE A MINIMUM COMPRESSIVE STRENGTH AT 28 DAYS OF 3,000 LB/SQ.INCH.



FOR DETAIL OF STEEL BOX SUPPORTS SEE DRG No Q/1026

SCHEDULE OF WIRE REINFORCEMENT FOR TOTAL No. OF 39 SLABS			
WIRE MARK	S.W.G. No.	TOTAL No.	WIRE LENGTH (INS.)
TA	20	2457	25·0
TB	20	234	9·4

NOTES.

REINFORCING WIRES TO BE CUT OFF FLUSH WITH EDGES OF CONCRETE SLAB

SEE REINFORCEMENT SCHEDULE ON THIS DRG. FOR TOTAL WIRES TO SLABS MARK M.T. 1.– M.T. 39. INCLUSIVE.

SEE "NOTES" MATERIALS ON THIS DRAWING

No. 39. OFF MARKS MT. 1.–MT. 39.

FIG 7 DETAILS OF $\frac{1}{10}^{TH.}$ SCALE SLABS.

REF.	PARTICULARS	BY	DATE
'A'	No. & LENGTH OF WIRES INCREASED.	V.A.N.	18.7.55.

AMENDMENTS.

TEST STRUCTURES		S.E. BRANCH. C.D. SECTION.	
MODEL R.C. TRENCH. SHELTER SLABS		BY	DATE
		DESIGN	
		DRAWN A.C.	
SCALE 3" TO 1 FOOT	DATE	TRACED E.J.H.	15.4.57
JOB No.		CHECKD M.J.	26.4.55
IDENT. No.		STRUCT. FILE No.	
DRG. No. Q/546 B		MINISTRY OF WORKS LONDON	

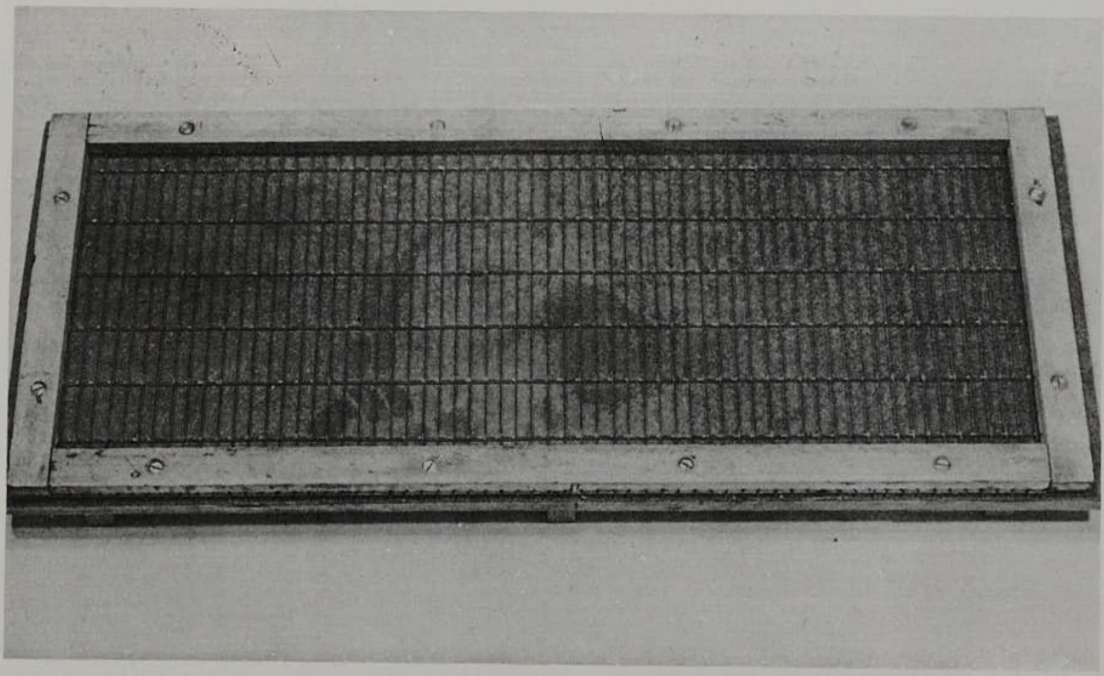


FIG. 8. $\frac{1}{10}$ SCALE MOULD READY FOR CASTING

FIG. 9. PANEL IN SURFACE IN POSITION BEFORE ENTRANCE SHAFT SEALED.

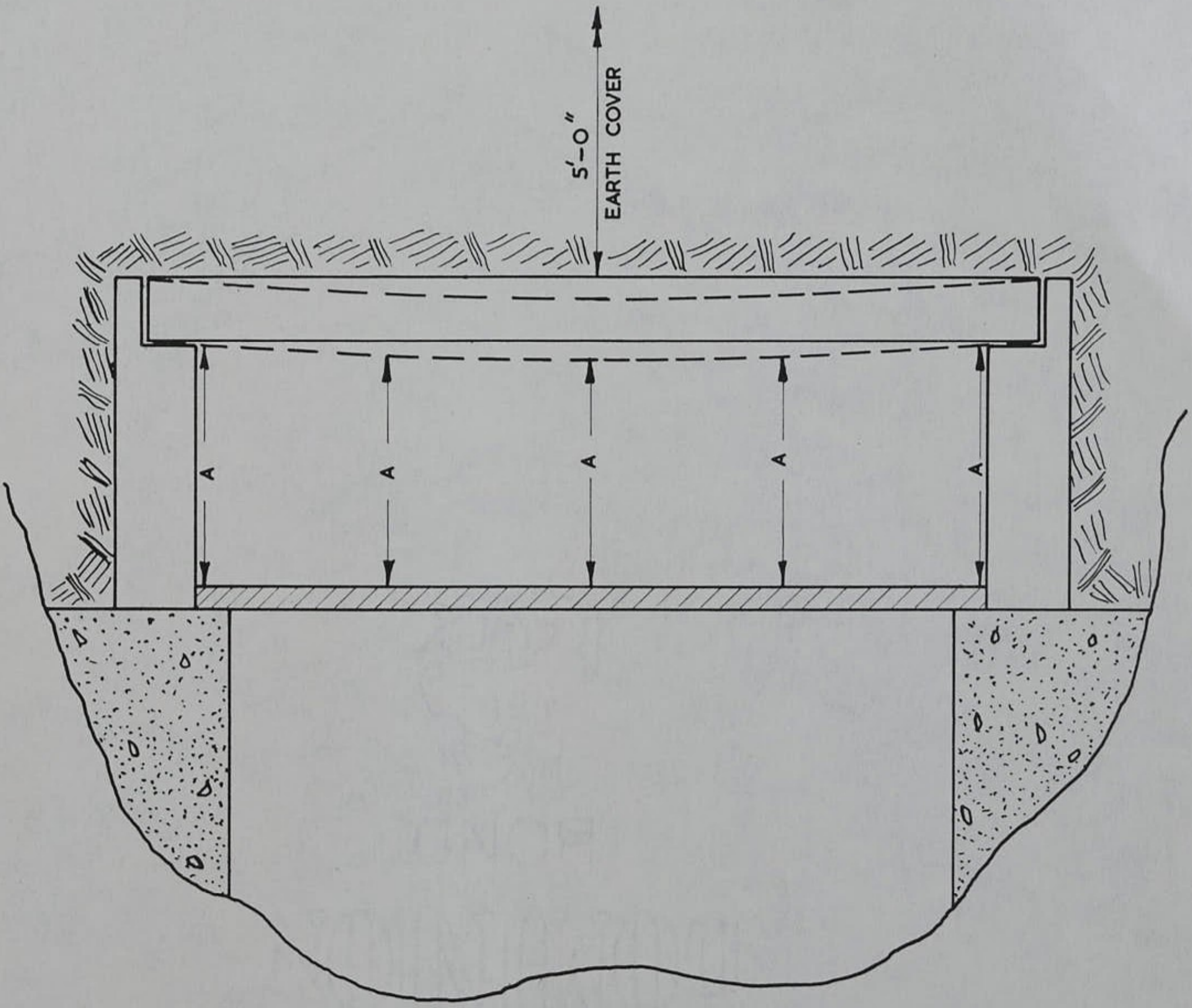


FIG. 10. SKETCH SHOWING METHOD OF MEASURING DEFLECTION OF PANEL WITH 5 FT EARTH COVER. MEASUREMENTS WERE TAKEN AT POINTS 'A'.

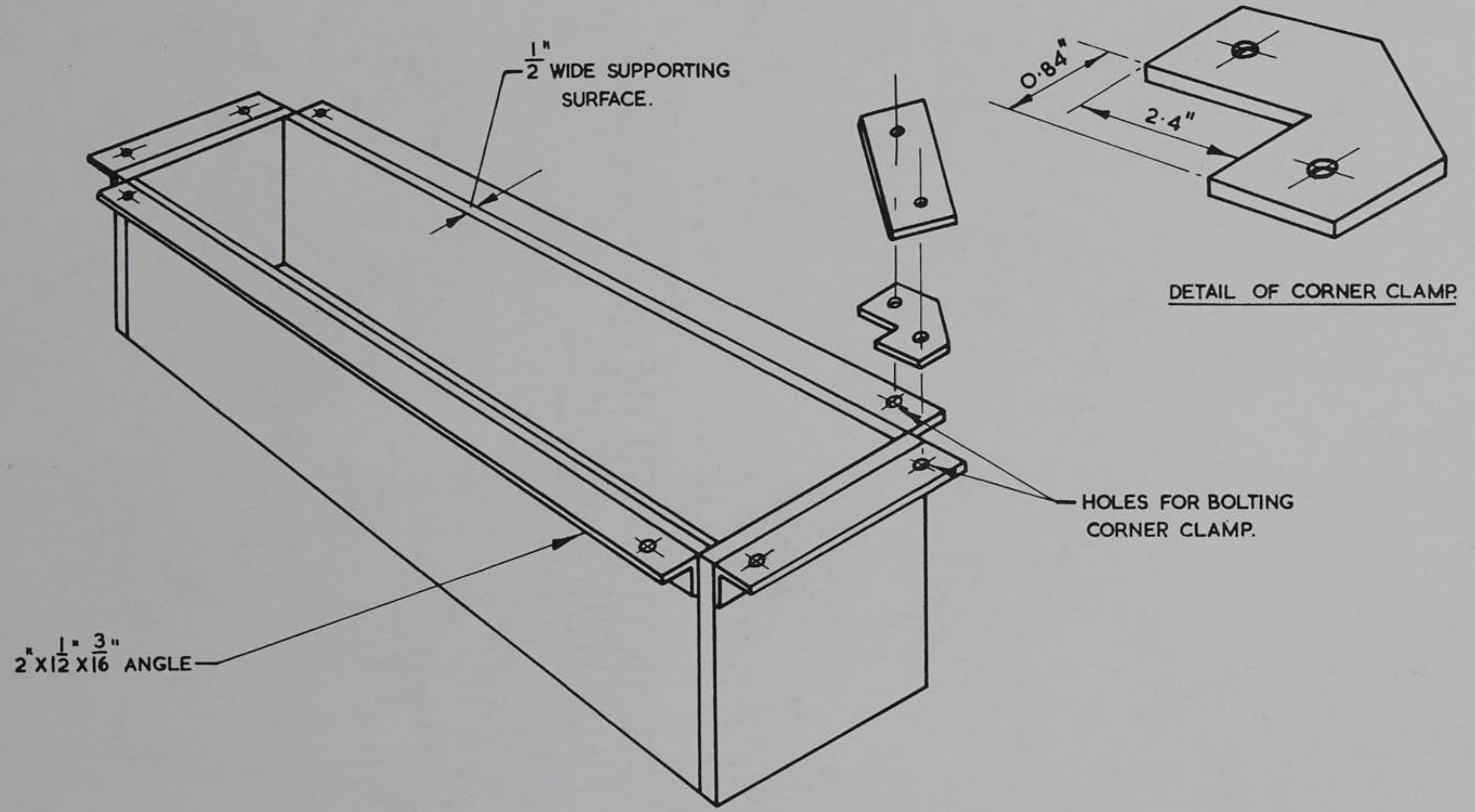


FIG. 11 STEEL BOX SUPPORT FOR MODEL PANEL.

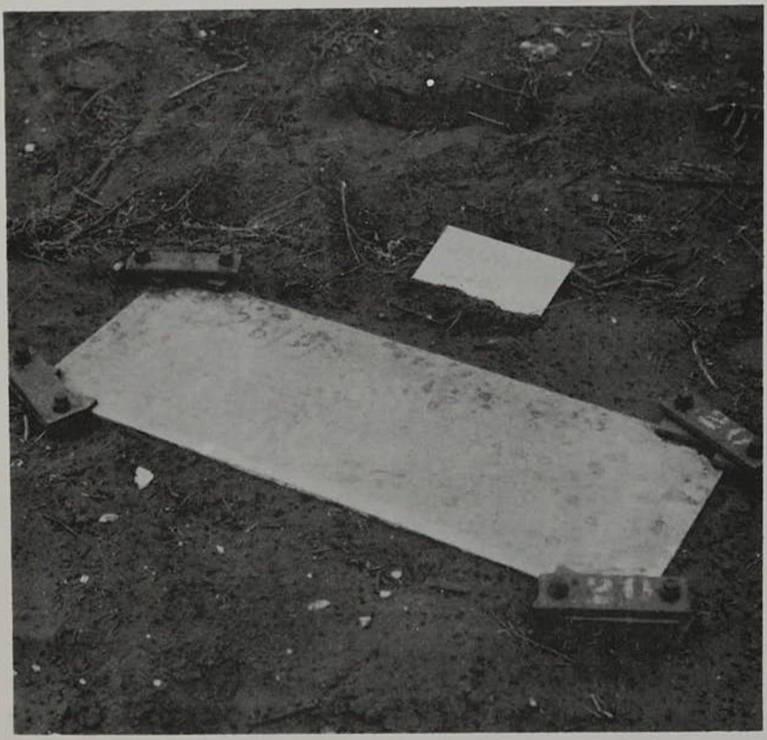


FIG 12 MODEL PANEL IN SURFACE BEFORE FIRING.

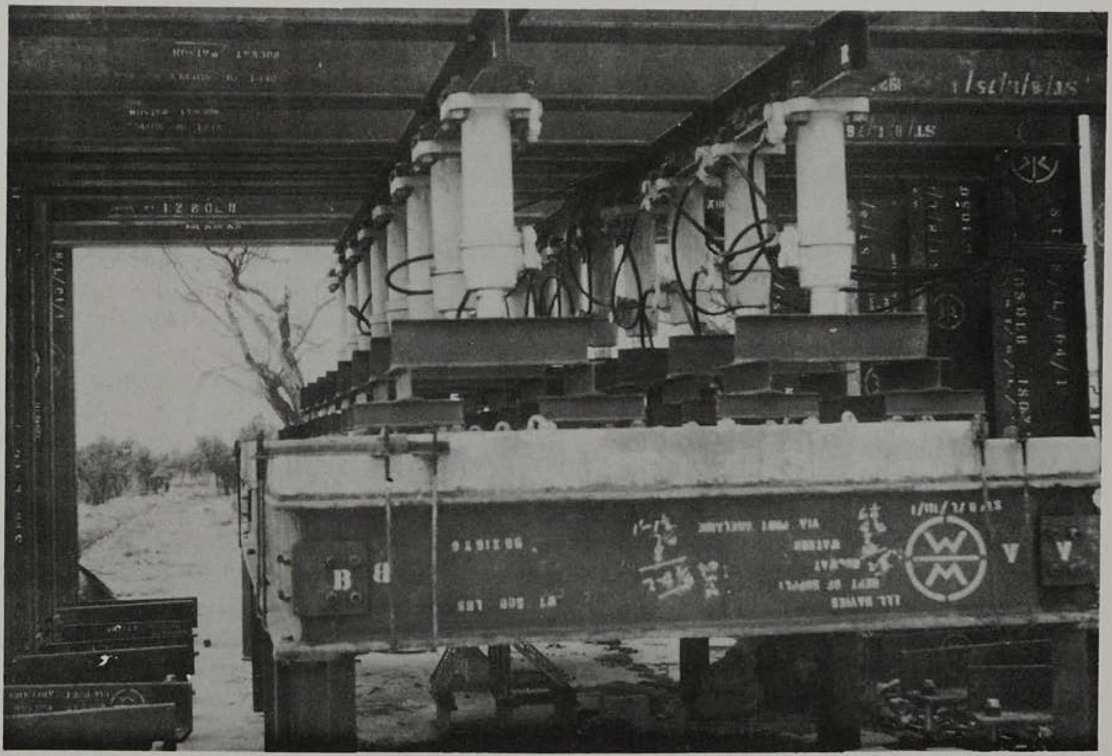


FIG 13 FULL SIZE PANEL SET UP IN TEST RIG READY FOR TEST.

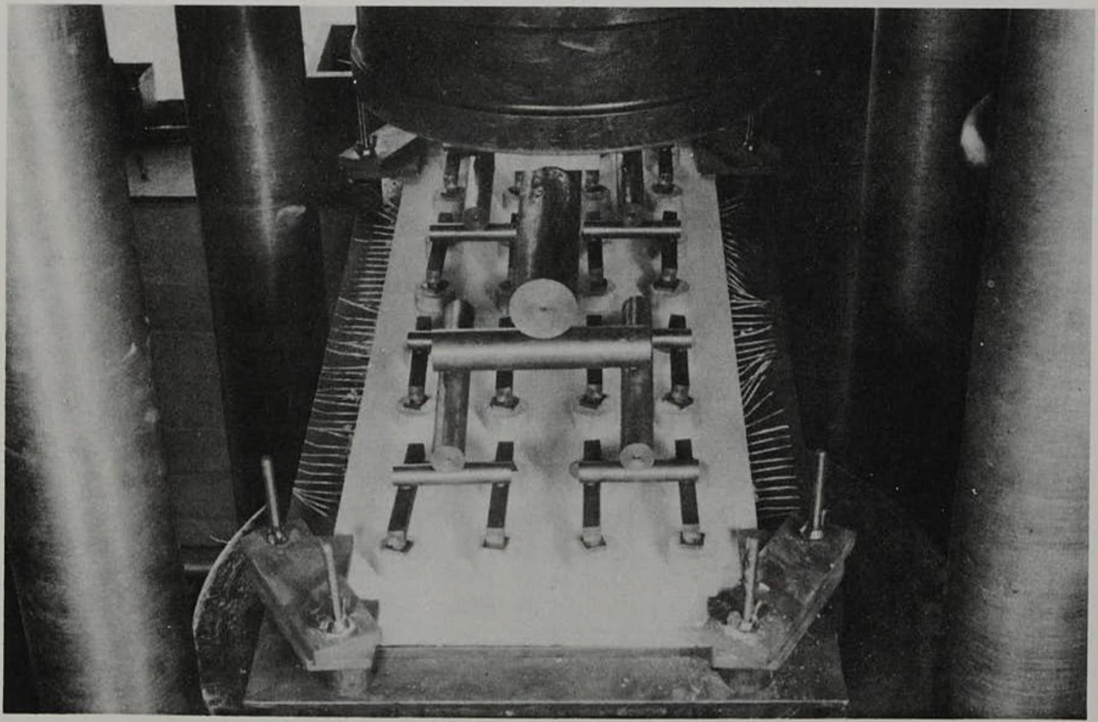


FIG. 14 PANEL READY FOR TESTING.

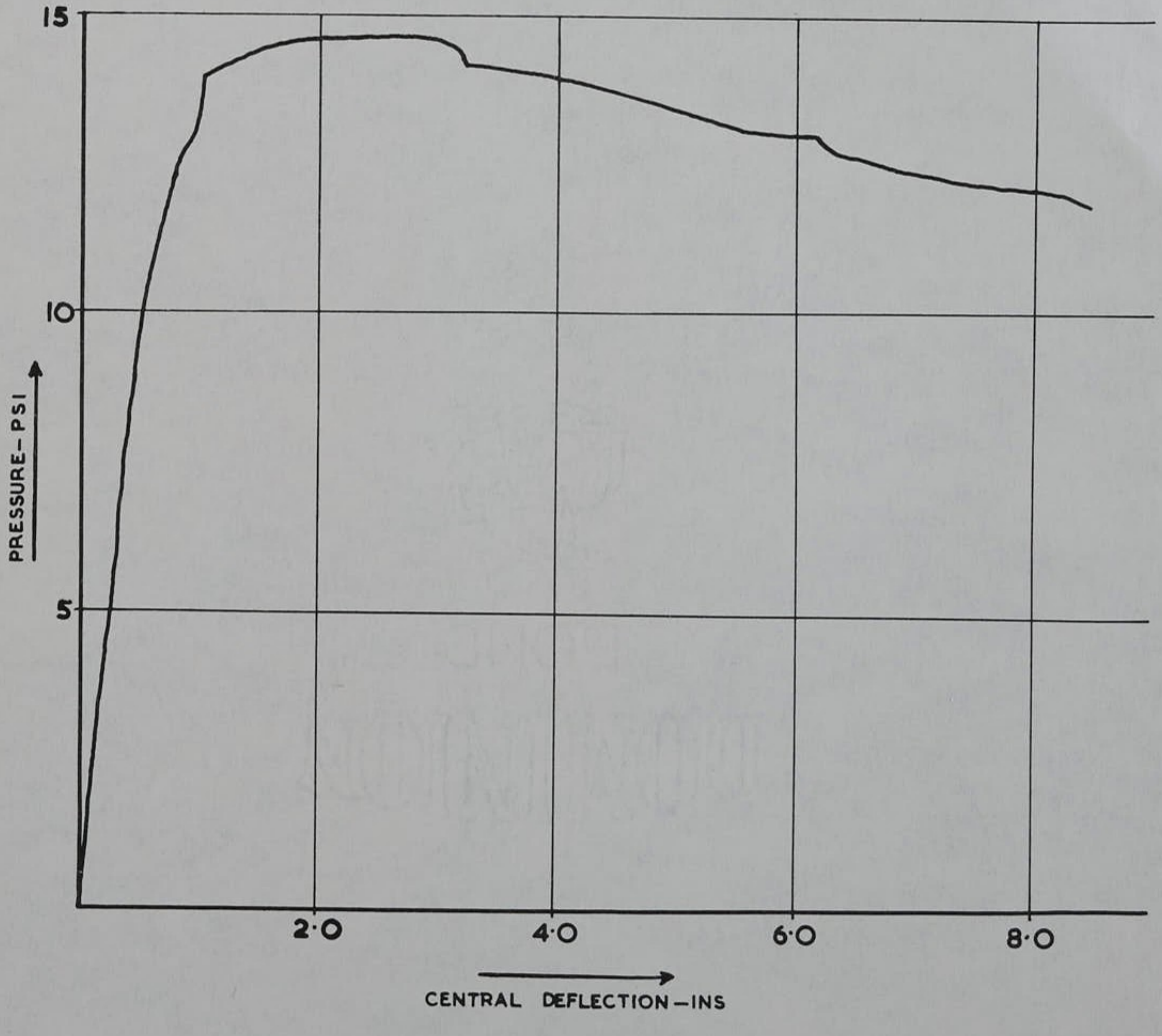


FIG 15 LOAD-DEFLECTION CURVE FOR FULL SCALE PANEL

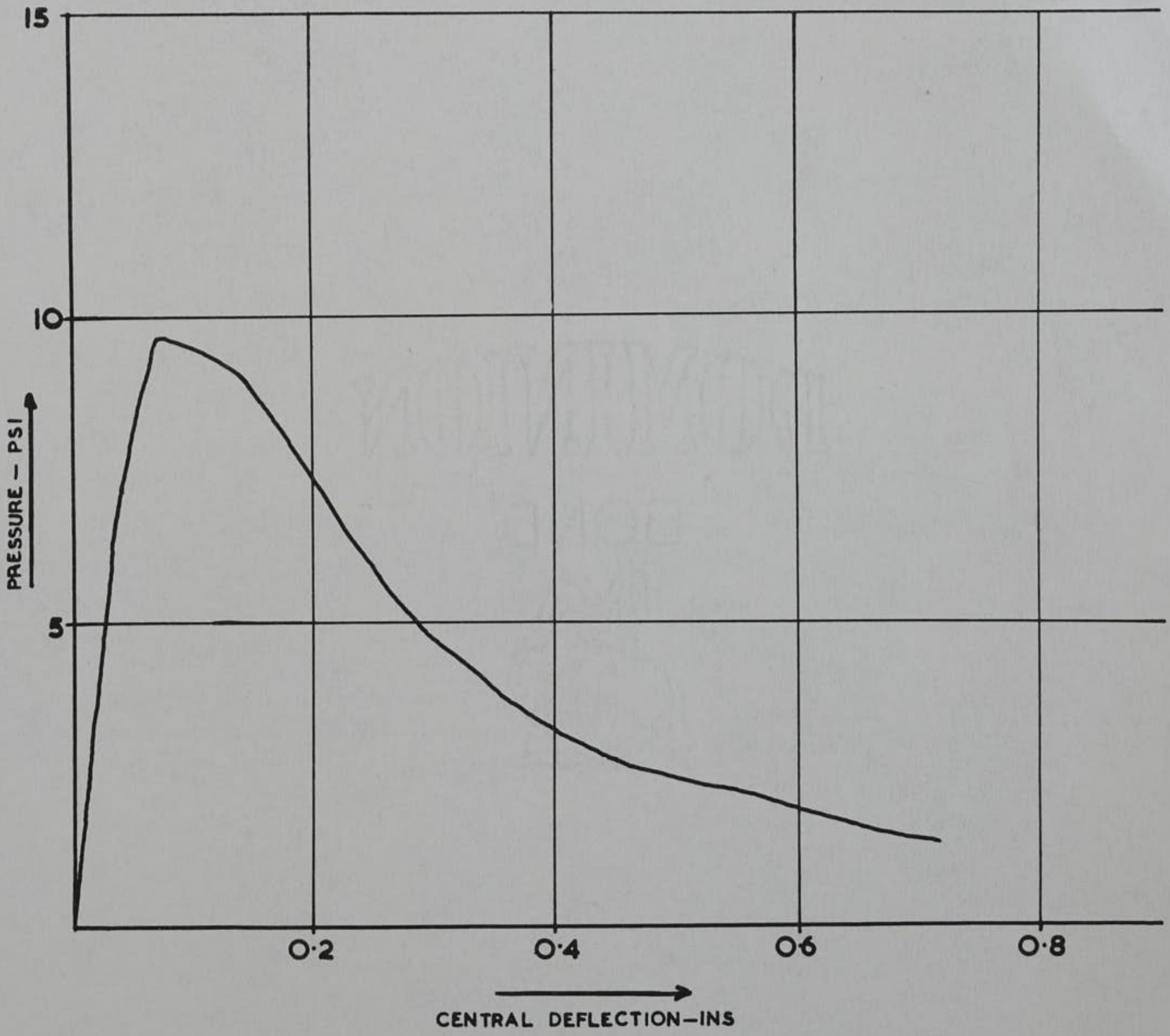


FIG 16 MEAN LOAD DEFLECTION CURVE FOR MODEL PANELS

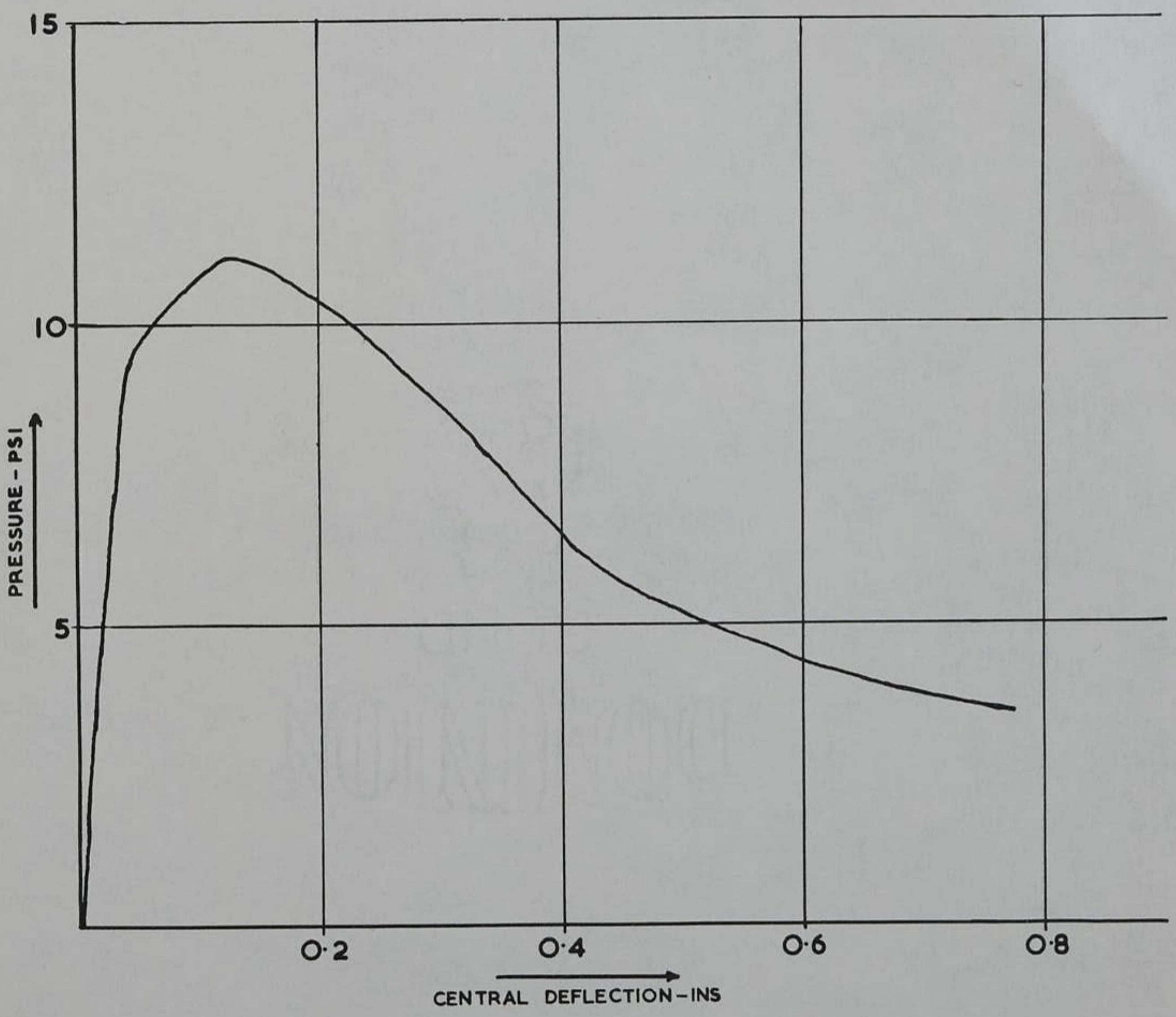


FIG 17. MEAN LOAD-DEFLECTION CURVE FOR MODEL PANELS CRACKED BEFORE TESTING

FIG. 18. DAMAGE TO FULL SCALE PANEL
AT 21·6 P.S.I.

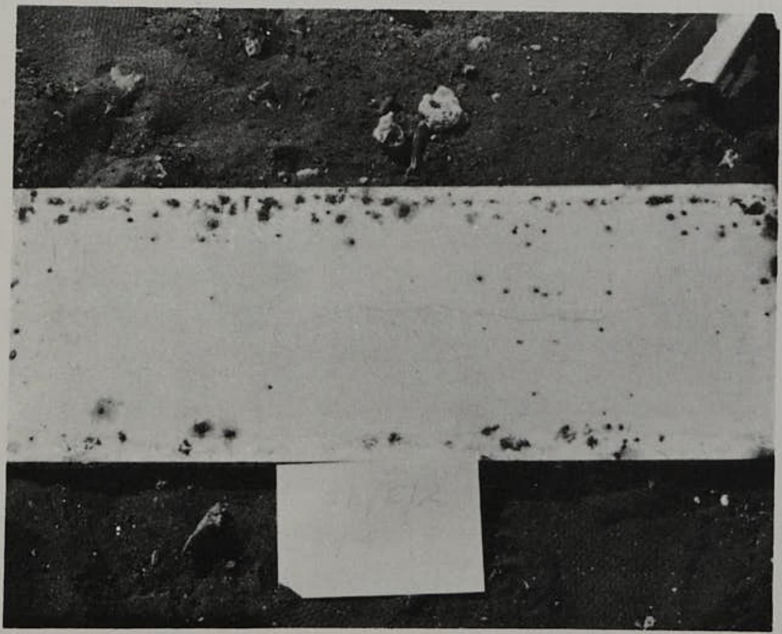
TOP

UNDERSIDE

FIG 19. DAMAGE TO MODEL PANEL WITH 6INS COVER

PRESSURE 17·9PSI RESIDUAL DEFLECTION 0·184INS

TOP



UNDERSIDE

FIG 20. DAMAGE TO MODEL PANEL WITH 6 INS COVER

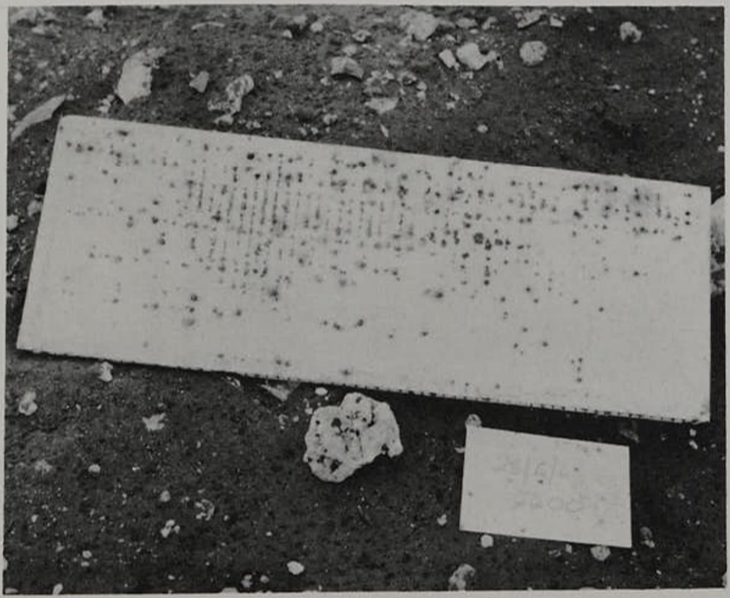
PRESSURE 17·9 PSI RESIDUAL DEFLECTION 0·127 INS

TOP

UNDERSIDE

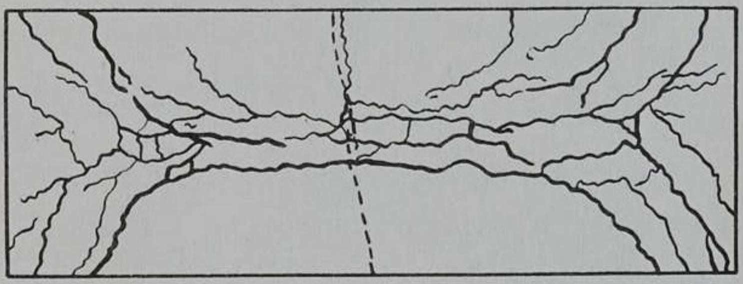
FIG 21 DAMAGE TO MODEL PANEL WITH 6INS COVER PRESSURE 13·2PSI RESIDUAL DEFLECTION 0·053INS

TOP



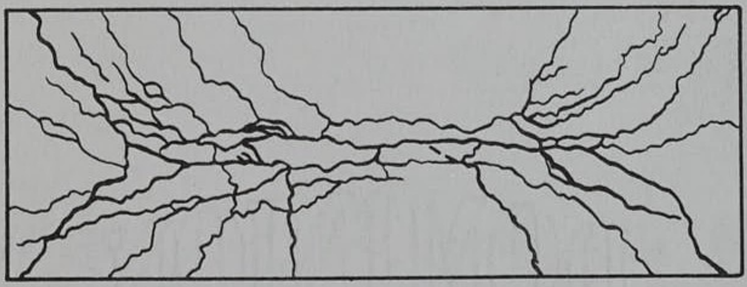
UNDERSIDE

FIG. 22. DAMAGE TO MODEL PANEL WITH 12 INS. COVER PRESSURE 12·0 PSI. RESIDUAL DEFLECTION 0·068 INS



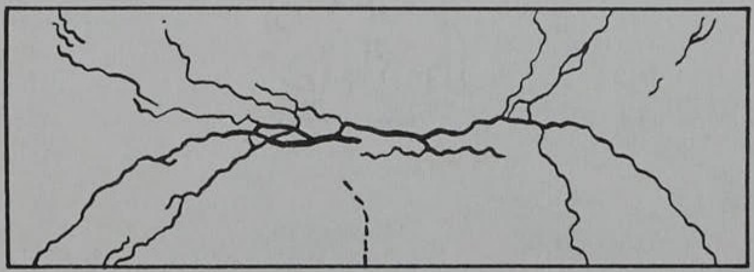
PANEL No 2a/A/2.

PRESSURE 27·0 P.S.I. RESIDUAL DEFLECTION 4·1 INS



PANEL No 2a/A/5

PRESSURE 17·9 P.S.I. RESIDUAL DEFLECTION 2·1 INS

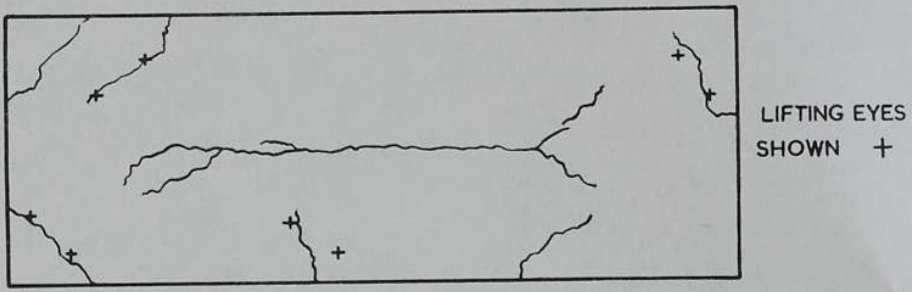


PANEL No 2a/A/7

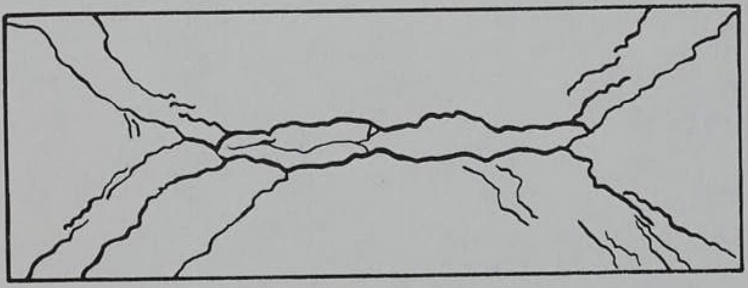
PRESSURE 12·0 P.S.I. RESIDUAL DEFLECTION 0·8 INS

FIG 23 CRACK PATTERNS ON UNDERSIDE OF FULL SCALE PANELS WITH 5 FT EARTH COVER AFTER FIRING.

BROKEN LINE SHOWS INITIAL CRACKING ON TOP SURFACES.



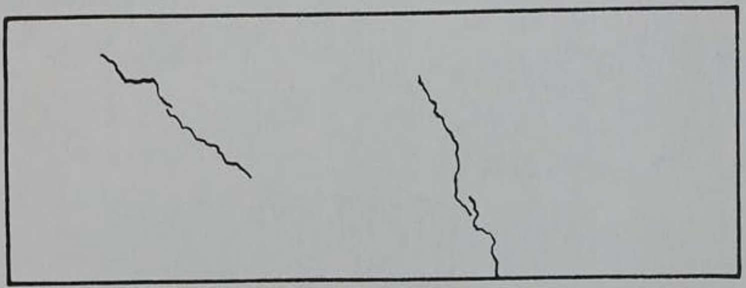
TOP.



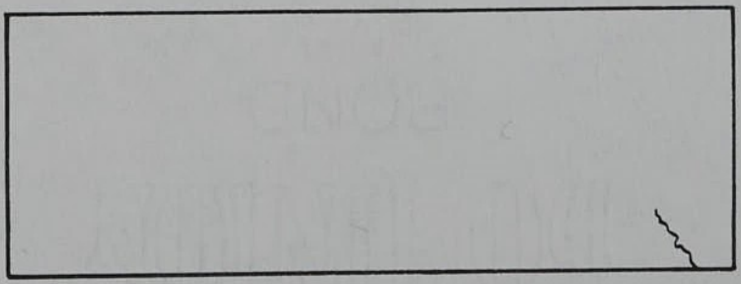
UNDERSIDE.

PANEL No 2a/A/6

PRESSURE 14·5 P.S.I. RESIDUAL DEFLECTION 0·9 INS.



TOP.



UNDERSIDE

PANEL No 2a/A/8

PRESSURE 10·3 P.S.I. RESIDUAL DEFLECTION 0·2 INS

FIG 24. CRACK PATTERNS ON FULL SCALE PANELS IN SURFACE AFTER FIRING.

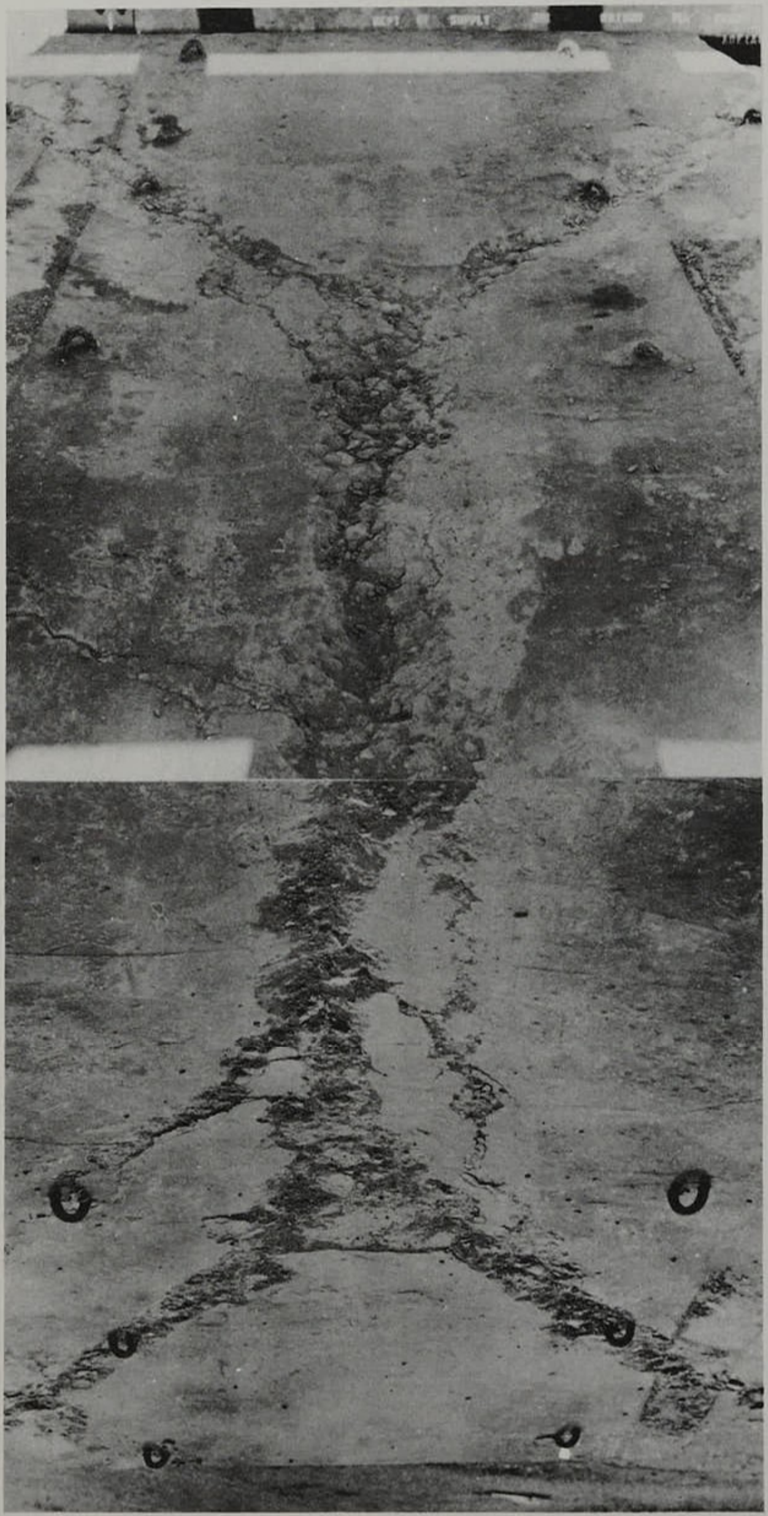
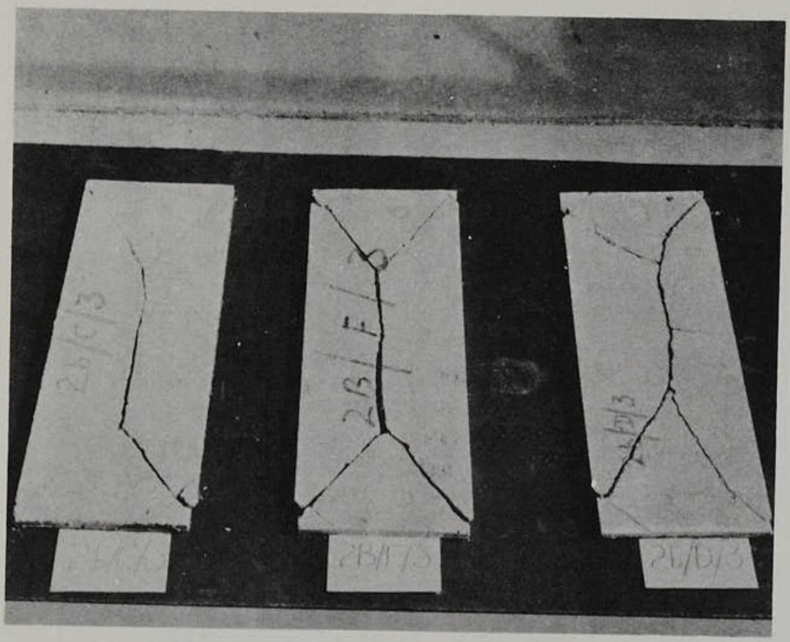


FIG 25. COMPOSITE PHOTOGRAPH OF TOP OF STATICALLY TESTED FULL SIZE PANEL



TOP

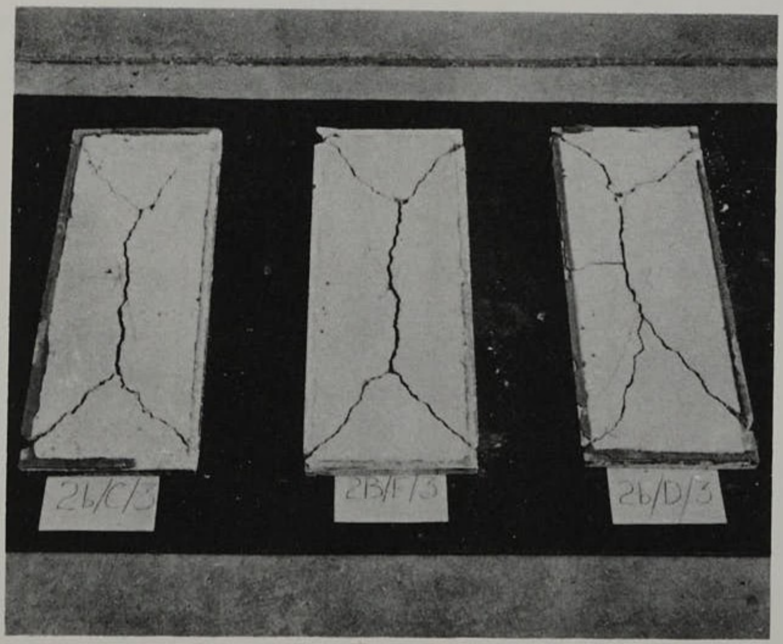


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FIG 26. TYPICAL DAMAGE TO MODEL PANELS UNDER STATIC LOADING

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Home Office,
Whitehall, S.W.1.

30th July, 1956.

Dear Forward,

You will remember that on 11th June your Minister wrote to mine suggesting that the implications of the proposed Memorandum on Public Control under Fall-out Conditions were of such importance that Cabinet approval should be obtained for its issue.

My Secretary of State agreed with this view and accordingly arranged for a suitable covering paper to be prepared. We were a little hesitant about circulating the paper while the recent discussions about the future level of home defence expenditure were going on, and it is only within the last day or two that we have been able to clear a paper for circulation. Major Lloyd-George has approved the paper, but has instructed that, as there is no possibility of it being taken before the recess, we should hold it over until a later date.

In accordance with his instruction I shall be arranging with the Cabinet Office for the paper to be circulated in due time, but I thought you might like to have this note about how the matter stood.

I am sending a copy of this letter to Gauld and to Perrin, whose respective Ministers are parties to the draft paper.

Yours sincerely,

R. R. Pittam

N. S. Forward, Esq.

E.R.

N.B.F.
I am ready to discuss with Home Secretary. I think after that we ought to mention to the P.M. W.M. 6/vi

Minister

P.O 1954

The Home Secretary wants to have a word with you about the political wisdom of issuing the memo. on radioactive fall-out to local authorities. I asked Mr Chilver to comment on & summarise the paper for you.
20/v.

SECRET

RCC/56/164

MINISTER OF DEFENCE

The object of the scheme of control outlined in the attached Home Office memorandum is to reduce the number of casualties from radiation sickness in the areas covered by fall-out after a thermo-nuclear attack.

Would it be prudent to mention these W.M. 11/vi

2. The scheme proposes that in a fall-out area the public should remain under cover, preferably in special fall-out refuges constructed in their houses, for the first forty-eight hours, during which the rate of radio-activity would decay to one-hundredth of the rate at one hour after the bomb had burst. Thereafter the permissible movement would depend on the intensity of the residual radio-activity. For this purpose it is proposed that the fall-out area should be divided into four zones, W, X, Y, and Z; zone W covering the fringes of the fall-out area and zone Z being the area of highest radio-active contamination. After forty-eight hours complete freedom of movement should again be possible in zone W, but in zone Z movement in the open would still be dangerous, but it would be possible to evacuate the population from the zone without exposing them to an excessive dose rate. The memorandum outlines the arrangements for giving warning of radio-active fall-out and the procedures for establishing the four zones within the fall-out area and of notifying them to the public. It also discusses how the evacuation of zone Z might be undertaken after the forty-eight hour period.

N.B.F.
1. M.A.C. Tuesday
2. Defence Cabinet Thursday
? mention there.
W.M. 11/vi
evacuation?

3. The Home Secretary wants to issue this memorandum to the local authorities but he would like first to discuss with you the advisability of doing so at the present time.

4. I suggest that there can be no objection to putting this proposed scheme to the local authorities. The scheme is at present only provisional and many aspects would in any event need to be discussed with the local authorities before more detailed arrangements could be formulated.

5. Despite the present pressure to reduce civil defence expenditure, it is surely unthinkable that we shall decide as a result of the present review of defence policy to wind up our civil defence services immediately. Such action would be liable to cause almost as severe a shock to N.A.T.O. as a unilateral decision to withdraw our forces from the continent. For the time being at least our policy must be to continue with civil defence, but at a lower tempo reflecting the reduced threat of war. During this period we must keep civil defence planning and training up to date. If the local authorities were to be given the impression we had lost all interest in civil defence, then either the civil defence services would begin to fade away or we should be faced with a demand for expensive measures to reinvigorate them.

6. This memorandum does not per se create a new demand for expenditure on civil defence. Without it, the local authorities are liable to be held up in developing their planning and training.

7. I understand that the Home Office also have in mind that this memorandum might be made available to the general public as part of the programme of education referred to in paragraph 102 of the Statement on Defence, 1956. I cannot see that this is called for, especially since the scheme of control is still only provisional. It is no use trying to educate the public in rather detailed plans of this kind in the present atmosphere. Admittedly, the issue of this memorandum to local authorities may well result in the outlines of the scheme becoming known to the public, but this would not matter.

8. From the point of view of general information to the public about the effects of fall-out, the memorandum does not in fact add significantly to the information that has already been published in the pamphlet on nuclear weapons which was issued earlier this year.

R.C. Chilver

Cabinet Office, S.W.1.
30th May, 1956

Author: Dr John McAulay, UK Home Office Scientific Adviser's Branch (see draft in their files in Nat. Arch.)

11th May, 1956

HOME OFFICE - SCOTTISH HOME DEPARTMENT

RADIOACTIVE FALL-OUT

Provisional Scheme of Public Control

NOTE: UK Home Office in 1956 published this as unclassified open: Manual of Civil Defence, vol. 1, Pamphlet 2. However, under ignorant political (Ministerial) demands, the reprint in 1957 was re-classified as "Restricted" for political fear it would lead to demands for increased interest in the credibility of civil defence, and further expense (though this was a trifle compared to nuclear expenditure!). (This exasperated CD Corps instructor John B. Cook into resigning in protest.)

HOME OFFICE - SCOTTISH HOME DEPARTMENT

RADIOACTIVE FALL-OUT

PROVISIONAL SCHEME OF PUBLIC CONTROL

(Prefactory Note:- The effects of gamma radiation on human beings, especially the cumulative effects of exposure to varying intensities over a period, is a subject on which, in the nature of the case, very little experience is available. Much research work will be required before the highest medical authorities can reasonably be expected to make their indispensable contribution to the plans for protecting the population from the residual radiation to be expected from a ground-burst megaton bomb. This provisional scheme has accordingly had to be drawn up on the basis of the best advice available at the time of its preparation.

The principles set out in the Memorandum and the details of the scheme are being referred by the Minister of Health to the Medical Research Council for their study and comment. It is hoped that it will be possible to reflect the views of the medical authorities in later versions of the Memorandum).

I. PRELIMINARY

1. Scope of the Scheme. This Memorandum outlines the principles and, to some extent, the procedure for securing control in areas affected by the residual radioactivity resulting from the explosion of a nuclear weapon burst on or near the ground. It is directed to establishing a framework within which more detailed planning of the activities of various essential services can take place and to providing a basis for the progressive instruction of the public on what they should do under fall-out conditions. The Memorandum has many limitations, and three of the most important should be recognised from the outset:-

(a) the proposed control procedure does not make provision for the special arrangements likely to be necessary for the control of rescue and other life saving operations in areas of moderate damage near to ground zero;

(b) the application of the control scheme in practice may be considerably affected by the period of time over which an attack on the United Kingdom extends. The institution of release procedures for the public must depend on decisions taken at the time in the light of the best appreciations of the balance of public advantage;

(c) no attempt is made to deal with contamination of growing crops and other agricultural hazards, e.g., to milk, nor with the difficulties confronting the principal public utility services such as water, electricity, gas, communications, transport or food distribution. For each of these fall-out presents serious new problems, which are being tackled by the Departments and services concerned in the light of the principles embodied in this Memorandum.

2. <u>Gamma radiation - background information</u>. The Home Departments' publication "Nuclear Weapons" (Manual of Civil Defence Vol. 1 Pamphlet No. 1) contains in Chapter III technical information on nuclear radiation hazards relevant to an understanding of the provisional control scheme. The table reproduced in paragraph 62 of "Nuclear Weapons" sets out the probable effects on people of a single exposure to gamma radiation. The problem of equivalent 'spread-over' doses is much more difficult but, on the best advice available and pending a considered appreciation from the Medical Research Council, it is considered that a dose of 60 roentgen spread over two or three days or 200 roentgen spread over a year would be no more likely to cause radiation sickness than a dose of 25 roentgen spread over three or four hours.

3. In addition to radiation sickness, the long-term effects of exposure to gamma radiation should not be overlooked. These include: reduced resistance to certain diseases; shortened expectation of life; and genetic effects. The present scheme sets out to safeguard the public, so far as possible, against the immediate dangers of fall-out and for this purpose the first objective must be survival in the aftermath period. This involves concentrating mainly on reducing the amount of radiation sickness. If such sickness can be kept to a minimum, the incidence of the long-term effects will also tend to be restricted.

II. PRINCIPLES OF THE PROVISIONAL SCHEME

4. General. The principle of keeping radiation sickness to a minimum is fundamental to the whole scheme. The average house can be made to give considerable, though not by any means complete, protection against radioactivity. It would be a question of using that protection to the best advantage. Theoretically, provided they were in adequately protected accommodation and had food and water, the longer people could avoid coming into the open the better. But, what would be theoretically sound under the best conditions, could not be adopted as a standard for the whole population in extensive areas. Theory needs to be reconciled with practical considerations. Thus the strain of close confinement would be considerable for adults let alone children, and the scheme would break down if it attempted to secure compliance with a discipline more severe than was demonstrably necessary in the interest of the people affected; moreover the earliest practicable release of areas flanking the main fall-out zones would be indispensable in so that the community could mobilise its resources to assist those in the more seriously affected areas.

5. The dominant characteristics of fall-out for which the scheme of control must allow are: (a) its persistance; and (b) the wide extent of the areas that will be simultaneously affected. The persistance of radioactivity makes it necessary to select a critical time after its appearance as the basis for defining permissible and recommended action. In the early stages decay would be rapid. Seven hours after the burst the dose rate measured in roentgen per hour might be one tenth of the rate at one hour; after two days the rate would be one hundredth. Thereafter radioactivity would continue to decay, but the reduction with time would become relatively less significant. This points to the adoption of 48 hours as the critical time for the initiation of action, especially in regard to the areas of highest intensity from which, as explained in paragraph 37, the population would have to be removed; further delay would not bring corresponding benefits. The plans of the public authorities would accordingly be based on a controlled resumption of activity in a large part of the fall-out area after about 48 hours. The precise timing would be a matter for decision at the time and might be affected by the general pattern of the attack. Care would in any case have to be taken to avoid creating in the minds of the public an expectation of a return to normal after a precisely determined interval; the public at large would have to be advised to be prepared to stay in their refuge for 2-3 days or more until they were told in any particular area under what conditions it was safe to come out.

6. The extent of the area affected would place a high premium on the greatest possible degree of decentralisation. The emphasis must necessarily be on self-help, and it has already been recognised that under fall-out conditions "the household becomes the basic unit" (Statement on Defence, 1956 - paragraph 102). The system of control by which individual households would receive guidance and help should evidently be based on the smallest practicable local units. These units would require to be linked with a central system of control and co-ordination, but should be able, if communications failed, to function to some extent on their own initiative. The need to have small units is reinforced by the fact that in parts of the fall-out area variations are to be expected in dose rates over comparatively small distances, and it would be important to avoid imposing precautions related to a particular dose rate over unnecessarily wide areas. Information and guidance related to local conditions must reach the street and hamlet or rather the individual household and farmstead if there is to be any worth while control at all. It is accordingly intended to adopt, for purposes of the control scheme, the unit of the wardens post area. It is recognised that this decision will have a considerable effect on the existing lay-out of wardens post areas and on the functions of the Wardens Service.

7. One further general aspect of the scheme deserves mention. There will be no means of knowing before the event the extent of radioactive contamination that will be caused by any one ground-burst megaton weapon. The intensity and extent of radioactivity and its distribution will vary within wide limits according to (i) the yield or power of the bomb; (ii) the extent to which the fireball is in contact with the ground i.e. the height of burst; (iii) the speed and direction of the wind at all heights up to about 100,000 feet; and (iv) the nature of the soil at ground zero. These uncertainties are a necessary element of the problem of devising a control scheme. Whatever their value for any given bomb, it will be essential to plan the scheme so that it could come into operation anywhere in the country and virtually simultaneously over very wide stretches of territory, perhaps in the greater part of two or three regions for one bomb. Moreover, except as a matter of short range forecasting based on meteorological conditions at the time, there can be no foreknowledge of where the highest intensities of radioactivity would occur. It follows that the aim should be for every wardens post unit - and indeed every household - to be prepared and equipped so that it could, if necessary, operate under the worst conditions of radioactivity. When warning of fall-out was given, it would be necessary for all to assume the worst until the actual level of radioactivity had been determined in respect of their own locality.

8. <u>State of Preparedness</u>. In elaborating this scheme it has been necessary to make some forecast of the degree of preparedness which it would be the Government's aim to achieve. Public education in these matters will be progressive during the next few years, and it is assumed that, if the threat of war increased, there would be some increase in the tempo of civil defence preparations by individuals no less than by public authorities. For present purposes the following assumptions have been made:-

(a) that the public at large would have been instructed - by means of a Householders' Handbook supplemented by intensive use of other means of publicity including broadcasting and television - in the measures each household should take to help itself. Such a handbook would, inter alia, give details of the control scheme and instructions as to the significance of the fall-out zones set out in paragraph 21 of this memorandum;

(b) that most households would, on Government advice, have obtained a sufficient stock of food and water to enable them to survive for a period - not less than one week's supplies should be the rule;

(c) that the great majority of people would have a fall-out refuge in their house or elsewhere giving a protection factor against radioactivity of 1/40. (See "Nuclear Weapons" - paragraphs 87 - 93). A ground floor room in a terrace house with the windows blocked with sandbags or equivalent would provide this standard of protection. Time spent in places with this protection factor is referred to subsequently as "In refuge"; and

(d) that elsewhere in a house, billet or at their place of work, everyone would have a measure of protection giving a factor of 1/10. Time spent in such places with this protection factor is referred to ~~subse~~quently as "Under cover".

9. Significance of Protection Factors for the Scheme. The factors proposed at (c) and (d) above are critically important for the determination of the classification of the fall-out area into zones which is the basis of the whole scheme. The general objective has been to divide the fall-out area into zones defined in terms of intensities of radioactivity and to work out a system under which the doses likely to be received by people in the different zones would result in few, if any, cases of radiation sickness provided that the control rules were complied with. The cumulative doses which would have to be allowed for would, as a general rule, be greater than those which it is proposed should be accepted by civil defence and other workers sent into a contaminated area from outside for a limited spell of duty.

10. No doubt many individuals would find better protection than the assumed refuge, e.g., in a covered slit trench in the garden, in a basement or in an under floor trench in the living room. Others, for a wide variety of reasons, might not have the benefit of protection as high as 1/40. They might be unable to improve the attenuation factor of their house or billet sufficiently to reach this standard, or they might not treat seriously a danger that they could neither see, smell nor touch. These variations must be accepted; they do not invalidate the approach adopted for this scheme. Disregard of the rules suggested for public behaviour, whether from bravado or ignorance, would bring its own penalty; there would be little in the way of enforcement in the ordinary sense of the term since neither police nor wardens would be able to patrol the fall-out area. If it became evident that an appreciable proportion of the population were to enjoy a higher standard of protection than 1/40, e.g., as a result of the extensive construction of purpose-built refuge rooms or shelters, the details, but not the principles, of the scheme would require review.

11. Scope of the Scheme. The scheme outlined in this memorandum is directed to laying down the lines on which the control of the public, assumed to be in their homes and billets, or at their places of work, should be organised. It does not make provision for the circumstances of hospitals and other comparable institutions, nor for persons in transit whether by road or rail when fall-out occurs, nor for the control of operational services, including the armed forces. The general principles of control will, of necessity, have to be adapted to apply to these and other special cases. The harmful effects of radiation will not, however, discriminate as between one individual and another and the plans of the various services will have to take account of the principles set out in this memorandum.

III. THE WARNING SYSTEM.

12. The development of a fall-out warning system supplementary to the system for giving warning of the attack itself is proceeding. The Royal Observer Corps will monitor fall-out so as to provide the Air Raid Warning Organisation with the data on which to base public warnings of fall-out. Warnings would be issued in the fall-out area wherever an intensity of radio-activity in excess of 0.3 roentgen per hour was expected to occur.

12A. At the present stage it is not possible to do more than outline the general objectives of the warning system, recognising that these will be modified in the light of experience as development proceeds. The extent to which the existing siren system can be adapted for the purpose remains to be determined. It is clear, however, that the public will need to know how they stand in relation to: (i) the attack; and (ii) fall-out. Effort is, therefore, being directed towards providing the following code:-

(i) The attack warning itself - the wailing note on a siren (or other signal device) giving warning of air attack, initiated by the warning message "Red".

(ii) Cancellation of this warning - warning message "White" - would also be by siren (or other signal device).

(iii) A warning of imminent danger of fall-out - by siren (or other signal device) hereafter called warning message "Black". This message would originate with the national warning organisation, though there may also be a need in certain circumstances for local origination of a fall-out warning based on actual readings and given by some means other than siren, possibly whistles. This warning would convey the meaning: "Go to cover and remain there until you are told what to do".

(iv) A cautionary fall-out warning - to be given by siren (or other signal device) to areas thought to be in the path of the fall-out. This warning - message "Grey" - would be based on forecasts of the probable path of the fall-out and would signify that there was serious danger of fall-out occurring, but that time was available for last minute precautions before taking cover. The question of a precise timing of the signal will have to be determined after further study of the possibilities of long term forecasting; but clearly it should forecast some minimum interval before the message "Black" would be issued to the district. Provisionally it might be regarded as signifying that one hour at least would elapse before the arrival of fall-out at the boundary of the Warning district nearest to ground zero.

There may also be a need for a wireless broadcast announcing that fall-out producing weapons have been used and giving guidance to the public on their behaviour. This might be in addition to, or in substitution for, the "Grey" warning.

13. The cancellation of the warning message "Black", i.e. the release of the public from the warning to take cover, would need

to be carried out on a combination of local and national information. The actual release would, in the main, have to be done locally and progressively, but to initiate the release procedure local controls would need to receive a "Blue" message signifying that: (a) fall-out was complete in the district; and (b) no further fall-out was threatened from any bombs already dropped. This message would permit the institution of local release procedures subject to a check of actual readings taken locally. To provide for the case where, in the event, "Grey" was not followed by "Black" it might be desirable to have a cancellation of "Grey" (by means of a "Green" message), though the same purpose could be achieved, with greater effort and some delay, by issuing a "Blue"; a "Green" message might also be used to cancel a "Black" message in areas where no fall-out had been deposited.

14. While responsibility for issuing the "Black" message and giving the warning signal would normally rest with the national organisation, special problems would arise in relation to the area of damage surrounding ground zero. In this area there might well be damage to warning devices or associated communications which in some cases would make it difficult for a nationally originated warning to be given. Moreover in the area damaged by blast and fire there would be urgent tasks to be carried out by civil defence personnel and the public, e.g., extinguishing small fires, giving first aid to casualties and removing exposed casualties to shelter. It would be neither practicable nor desirable to attempt to keep everyone under cover in such circumstances, since fall-out might not occur throughout the area, and, where it did, there might be some delay in its appearance which could be profitably employed in life saving and other urgent tasks. There would be a need for special local arrangements in such areas to give warning when a significant degree of fall-out was detected.

15. It would be particularly important to ensure that the public were aware that a "Black" warning was still operative in their areas. A prolonged warning without clear evidence of its cause will be apt to lose its effect and be disregarded. Wireless broadcasting under the control of regional headquarters may be a useful means of emphasising the continuing threat, but some kind of visual signal may prove practicable in some areas.

16. The following is a summary of the possible warning pattern:-

Message	How Given	Meaning
	A. Attack Warning Messages	
Red	To the public (by siren or other signal device)	Imminent danger of attack - take cover.
White	To the public (by siren or other signal device)	Raiders Passed.
	B. Fall-out Warning Messages	
Grey	To the public (by siren or other signal device)	Danger of fall-out but at least one hour before its expected arrival.

Message	How Given	Meaning
Black	To the public (by siren or other signal device)	Imminent danger of fall-out - take cover until further advice is received by word of mouth.
Blue	To controls by telephone	Fall-out complete and no further fall-out threatened from any other bomb already dropped. Release procedures may be initiated.
Green	To the public (by siren or other signal device)	Cancellation of Grey or Black.

NOTE: The messages have for convenience been grouped under two heads. This should not be taken as indicating the sequence in which they might occur. In particular a Grey message might be issued to areas where the Red attack warning was still in force.

IV. CATEGORISATION OF ZONES.

17. The basis proposed for the scheme of control is the categorisation of fall-out areas into zones of radiation intensity in relation to each of which a drill to be observed by the public can be prescribed. In this and the succeeding sections the zones are described. The method of establishing them and the bearing of the proposals on the responsibilities of the civil defence and other services are considered in a concluding section.

18. The letters W, X, Y and Z would be used to identify four kinds of zone. The zone category would, for the most part, be determined by the dose rate in roentgens per hour (r.p.h.) at 48 hours after burst, i.e., as a general rule 1/100th of the rate at 1 hour. This basis of definition is proposed to be adopted chiefly for the reasons given in paragraphs 4 and 5, but there are also the following grounds for its adoption:

(i) the dose rate at 1 hour would, over large parts of the fall-out area, be a theoretical rather than a practical concept, since the fall-out would not have travelled far in the first hour and at most would only be complete close to ground zero;

(ii) generally, except in Zone W (see next Section) or in the damaged area, no action out of doors is required or should be encouraged, in the fall-out area within the first 48 hours;

(iii) there would be advantages in basing action in the fall-out area on a predicted dose rate at 48 hours which could be verified from instrument readings at the time. This would provide a safeguard against any variation in the decay rate and a check on predictions based on the dose rate at 7 hours (1/10th of the rate at 1 hour) which would be used for the provisional determination of boundaries.

19. The determination of fall-out zones and the institution of the control plan would be a process independent of operations by the civil and military forces to deal with casualties and damage in the area close to ground zero. Such operations, which would call for a balancing of the radiological hazard to the participants against the results they might be able to achieve in a given time, could best be conducted on the basis of actual dose rates measured at the time.

20. As explained in paragraph 7 any estimate before the event of the area which would be affected by fall-out can at best be speculative; it is clear, however, that it is necessary to think in terms of some thousands of square miles. The data published in respect of the American nuclear weapon test in March, 1954, refer to an area of 7,000 square miles in which survival might have depended on prompt evacuation of the area or upon taking shelter and to an area of 14,000 square miles in which a cumulative dose in the open of 100 roentgen or more was recorded in the 24-48 hours after the detonation. The control scheme, if it is to achieve its object of keeping sickness to a minimum, would have to operate in the initial stages in respect of even lower doses than this. The area affected by fall-out from a megaton weapon attack would probably be of such dimensions as rarely to develop its full extent over the land surface of the United Kingdom. A ten megaton bomb might well result in an actual dose rate of 0.3 r.p.h. being measured up to 1,000 miles from ground zero and the contaminated area might at its widest part be 80-100 miles across. Within this area the territory in which control measures would need to be observed after the initial 48 hour period (Zones X,Y and Z) might still be of the order of 500 x 40 miles.

21. The following table gives a summary definition of the zones and the recommended and permissible action in them:-

<u>TABLE FOR INCLUSION IN PARAGRAPH 21.</u>

Zone	Definition of Zone Boundaries	Range of Cumulative Dose in open at 48 hours.	Summary of permissible and recommended action	Range of Cumulative Doses assuming observance of control rules.
W	Outer: Limit of area placed under "Black Warning" (See Footnote). Inner: 0.3r. at 48 hours	Up to 80 r.	Complete release from refuge as soon as dose-rate falls to 0.3 r.p.h. or, if the rate has not reached that figure, when fall-out is complete.	At 48 hours 2 r.
X	Outer: 0.3r. at 48 hours Inner: 3r. at 48 hours.	80 - 800 r.	Qualified release from refuge after 48 hrs. - indoor workers to follow normal occupations, but not to exceed 4 hrs. per day in the open. Outdoor workers to work half shifts for next five days. At the end of this period the zone would be normal, except that all would be advised to be out of doors as little as possible and not in any case to exceed 8 hrs. per day in the open for the next three months.	At 48 hrs. 2 - 20 r. Next 5 days 6 - 50 r. Next 4 wks. 12 - 120 r. Next 2 mths. 14 - 145 r.
Y	Outer: 3r. at 48 hours. Inner: 10r. at 48 hours.	800 - 2,800 r.	Release from refuge under stringent control after 48 hrs. For the next 12 days people should not leave their refuge for longer than necessary. Time in the open should not exceed 2 hrs. per day and time under cover, but not in refuge, a further 8 hrs. On this basis essential indoor workers should be able to get to their places of work, but outdoor work would remain suspended; a relaxation would be possible after the first fortnight and further easement in another three weeks. For the rest of the first year, however, people in this zone should not exceed 8 hrs. a day in the open.	At 48 hrs. 20 - 70 r. Next 12 days 50 - 170 r. Next 3 wks. 70 - 240 r. Next 2 mths. 95 - 330 r.
Z	10r. at 48 hours.	Above 2,800 r.	All movement outside refuge accommodation in this zone would be dangerous. People should remain in refuge until instructions for clearance are given - they should then leave the zone by the quickest available route if they have means of transport or wait in their refuge to be collected if they have not. The clearance operation might start after 48 hrs. and removal from the zone would be for at least 3 months.	At 48 hrs. - Above 70 r.

After 48 hours Zone W would for public control purposes have disappeared. Its outer boundary would have moved during that period to coincide with the outer boundary of Zone X. The true outer boundary of the zone would be the contour at which the dose rate in the open was never in excess of 0.3 r.p.h. which is, for practical purposes, the lowest reading which can be reliably taken with the existing radiac survey instrument. In practice the initial Zone W boundary would be defined in terms of the boundaries of a series of warning districts on the flanks of the fall-out. The question of defining an area extending in some places beyond Zone W in which there might be an agricultural hazard is being studied.

V. ZONE W.

22. Characteristics of Zone W. Zone W would cover the fringes of the fall-out area. It would be potentially a very extensive area indeed, but in the United Kingdom would be unlikely to develop its full extent before reaching the coast. Its outer boundary would initially be constituted by the limits of the warning districts in respect of which a warning message "Black" was issued signifying imminent danger of fall-out; its inner boundary would form the outer boundary of Zone X. During the first 48 hours Zone W would contract as the dose rate fell below 0.3 r.p.h. After 48 hours the zone would cease to exist for public control purposes, though an agricultural hazard might remain.

23. The proposals for Zone W are designed to ensure that no one would get a short term dose of more than 6 r. even if he spent the whole of the next 12 hours in the open after being released; it is not proposed to impose any greater restriction on anyone than would be consistent with the attainment of this objective. Given good discipline in the first 2/3 days, all the people in this zone would be able, without restraint, to play their full part in the work of restoration, decontamination and recuperation. The aim would be progressively to release them all at the earliest moment it was safe to do so. After release they would be able to regard themselves as unaffected by radiation and would be able, if required, to enter and work in more heavily contaminated areas on the same terms as people not affected by fall-out at all.

24. Establishing the outer boundary. The first problem would be to establish an outer boundary and to guard against traffic crossing the boundary and penetrating into the fall-out area. The necessary action would have to be taken outside any area to which the "Black" fall-out warning was given. As soon, therefore, as a warning district received the "Black" warning it would be for all the wardens posts immediately outside the boundary (except any which were themselves already under the "Black" warning or received it concurrently) to put up notices on the boundary of the "Black" district bearing the legend:-

"DANGER - FALL-OUT"

25. The technique for carrying out the posting of warning notices will require to be worked out both generally and in detail. At this stage it is sufficient to say that through roads, especially trunk roads, would receive priority of attention. The exhibition of notices would not entail the setting up of road blocks or the risk of exposure of personnel to radioactivity. The purpose of the notices would be informatory, i.e. to ensure that no person or vehicle proceeded further along the road in ignorance of the danger they might run. This procedure would have to be followed whether or not the posts on whom the duty fell were themselves under the "Red" or "Grey" warning.

26. Contraction of Zone W. By the means outlined in paragraph 25 a provisional control line would be established on both flanks of the fall-out area along the boundaries of the warning districts under the "Black" warning. During the next 48 hours the objective would be systematically to release the area within the control line up to the boundary of Zone X and to do this as rapidly as possible. This would be achieved by adding individual post areas or groups of post areas to the free zone beyond the provisional control line as soon as it became safe to do so. The general criterion for this purpose would be when the radioactivity reading for a particular area, or areas, had fallen to 0.3 r.p.h. As the radioactivity decayed, the true 0.3 r.p.h. line would move continuously towards the fall-out axis at a speed which is, however, unlikely to exceed ½ mile in an hour; it would move even more slowly where the contours were

closest together near to ground zero. The Zone W boundary would contract in rough conformity with this movement (see paragraphs 50-52).

27. <u>Release procedure.</u> For a variety of reasons, which would apply with even greater force to the higher intensity zones, release of the public from restrictions after fall-out had occurred could not be effected by a general siren signal. When an area was released, it would be necessary to ensure that everybody in it was made aware of the conditions applying to that area and of such continuing precautions as they should, in their own interest, observe. In the main, this would have to be done by wardens on a basis of house to house notification, though in some cases it might be possible to speed up the process e.g., by the use of public address equipment mounted in vehicles.

28. The inhabitants of a released area in Zone W would be told that they had been in such a zone, that they were now free of all restriction, that they were unaffected by radioactivity, but that they should conform with the public notices marking the limits of the free zone. Wardens would initiate release action on being authorised to do so by their local control.

VI. ZONE X

29. Characteristics of Zone X. This would be a zone of comparatively light contamination; its extent would, however, be considerable, perhaps 450/600 miles long and 35/50 miles wide for a 10 megaton weapon. It would be a zone in which, once the period of 2/3 days after burst had elapsed, something closely approximating to normal working conditions would have to be restored forthwith; the area should cease to be a liability on the rest of the nation, except perhaps as regards agricultural products. The dose rate in the area, which would have ranged from 30 r.p.h. up to 300 r.p.h. at 1 hour after burst, would have fallen to between 0.3 r.p.h. and 3 r.p.h. The dose received by people in the area at the end of 48 hours, assuming they had spent this time in refuge, would have been between 2 r and 20 r. For the rest of the first week (i.e., the next five days) they should not spend more than 4 hours per day in the open, but freedom for up to 4 hours should enable the great majority of people to go about their normal business. For the remaining 20 hours of each day they should be advised to spend as much time as possible in their refuge, but in any case indoors. Provided they remained under cover, their dose would not be seriously increased. At the end of the first week people in Zone X would be freed from restraint. If the time such people would, on average, thereafter subsequently spend in the open is put at 8 hours per day, the cumulative dose of people in the zone would, assuming a protective factor of 40 for their refuge, lie between 14 and 145r. at the end of three months with a possible further increase of 2 - 25r. during the remainder of the first year. These figures have been calculated on a basis which excludes further possible reduction by the physical removal of contamination, e.g. down the drain whether by weathering or decontamination; it is accordingly reasonable to assume that very little, if any, radiation sickness would occur in the zone, but there would be some long term effects. It is possible that the cumulative doses would be reduced if effective decontamination could be undertaken both by householders and the public authorities, but there are considerable practical difficulties about this.

30. Further consideration will need to be given to the position of outdoor workers in the zone, many of whom perform duties of first importance - agricultural workers, police, transport staffs, etc. Strict control of their hours of work after the general release took place would be an obvious requirement.

31. Establishment of the boundary and release procedure. The outer and inner boundaries of Zone X would be determined in accordance with the procedure described in Section IX of this memorandum, and the roads crossing the inner boundary (which would also be the outer boundary of Zone Y) would require to be marked after the lapse of 48 hours in the same way as described in paragraph 24. The marking boards would be more mandatory in character, e.g.,

"DANGER - FALL OUT

ZONE Y STARTS HERE

NO ENTRY"

When the word for release was given, wardens would have to use the time they were permitted to spend in the open notifying the inhabitants of their areas that they were in Zone X; that they could leave their houses for limited periods, but should spend as much time as possible indoors under cover either at home or at their place of work. For the next five days they should avoid being in the open as far as possible and in no case for more than 4 hours a day. They should not regard themselves as available for work in the higher intensity Zones Y and Z, but could play a very significant part of preparing aid for those in Zone Y. Any household who wished to leave the zone and had the means to do so could not be prevented from moving, but they should be warned of the congestion likely to be found elsewhere and of the dangers of being unable to find adequate shelter in the event of another attack. They should be encouraged to recognise the greater claim of others to leave the innermost zone and to exercise restraint by staying put.

VII. ZONE Y

32. Characteristics of Zone Y. In this zone stringent precautions would be essential; initial dose rates in the open might have been as high as 1,000 r.p.h. Though much smaller than Zone X, it would still cover a large area; a 10 megaton weapon might give rise to a Zone Y up to 20 miles wide and some 200 miles long. Even after 48 hours, the dose rate in the open would range between 3 r.p.h. and 10 r.p.h. and the inhabitants of the zone (who, if in refuge affording a protective factor of 40, would already have taken between 20 and 70r) would, if they were not to become sick, have to act with discipline and discretion. Virtually their only concern for the whole of the first fortnight would be with their own radiological safety. For this period they would need to restrict the time spent out of doors to, say, 2 hours per day at most, and the time which they spent out of their refuge but under cover to a further 6 hours per day. Even after 14 days, they would need to continue to remain under cover as far as possible, and should not in any event be in the open for more than 4 hours per day for the next three weeks; and 8 hours per day for the rest of the first year. Assuming observance of such a discipline the cumulative dose of people in the zone would lie between 95 and 330r. at the end of three months and between 125 and 430r. at the end of the first year.

33. After the first 2/3 days, Zone Y would begin to come to life again. There should not be much sickness in the zone having regard to the time over which the dose of 20 - 70r. would have been spread. The bulk of the people in the zone must, however, continue to stay within doors and be prepared to nurse such of their number as fell sick without aid or advice other than such general guidance as might have been issued beforehand or be relayed to them by broadcast. It would be important to ensure that the permissible two hours in the open was turned to good account. Within households there would be scope for spreading the risks by sending out individual members to perform necessary services for all. Careful organisation would be required to avoid more people emerging at the same time, e.g., to get food, than could be attended to promptly. It is to be hoped that many, if not most, of the people would contrive to spend less than the allowed time in the open; they should not in any event go far from their homes or billets. Properly utilised, the two hours should none the less enable them to exist under tolerable conditions. It would permit visiting of near neighbours and short journeys to get essentials, preferably by bicycle or car. Only the most urgent of outdoor tasks would be able to be performed by people already in the zone, but key personnel required as reliefs for the operation of essential services would be able to report for duty provided protection was available for them at their places of work.

34. As with Zone X, people should be discouraged from leaving the zone. The keynote of policy should be that people in the zone were safe, provided they were sensible and observed the recommended precautions. The departure of those who had the means to take themselves out of the area could, however, hardly be prevented; indeed it might be that some arrangements for removing young children with their mothers would prove to be feasible. The transit dose of radiation for a journey by car from the inner contour of the zone after 48 hours would amount to about 3 r.

35. Establishment of the boundary and release procedure. This would not differ in principle from the corresponding action in Zone X. Each warden would have less time in which he could be expected to play his part in establishing contact with householders to give them guidance on the local situation. The arrangements for marking the inner boundary of the zone (i.e.,the beginning of Zone Z) would be of less urgency and importance, than in the outer zones.

VIII. ZONE Z.

36. Characteristics of Zone Z. The dose rate in this zone would have been 1,000 r.p.h. or more at one hour after burst; at 48 hours it would still be 10 r.p.h. in the open at the outer contour. Assuming people in the zone to have had the benefit of a protective factor of 40 in their refuges, the minimum cumulative dose would be about 70r. and much higher doses would have been received in parts of the zone. On its outer fringes, the zone would contain people for whom there would be good hope of escaping any serious effects. Further towards the fall-out axis and closer to ground zero, sickness, of which symptoms might be beginning to appear after about 48 hours, would be general. In the inner part of the zone, especially in the heavily damaged area towards ground zero, lethal doses of radiation would have been received by some, and the entire population would be suffering various degrees of incapacity. The chances of ultimate survival of many of these might be slender.

36A. The 10r at 48 hours contour might extend for a distance of 70 - 100 miles from the ground zero of a 10 megaton bomb; it might enclose an area up to 12 miles wide. These figures, like other zone dimensions given in this memorandum, need to be treated with reserve; they provide an indication of the scale on which control operations would have to be conducted - no more. In the case of Zone Z there are special grounds for emphasising this factor: not only must allowance be made for the variables affecting fall-out mentioned in paragraph 7, but decisions taken in the aftermath of the attack might critically affect the determination of the zone boundary. The action to be taken in respect of the zone, as the following paragraphs show, would be drastic, and there would be a consequent need for flexibility in the classification of post areas on or near the boundary e.g. by the adoption in places of another (higher) contour. The weight of the enemy's attack and the resulting situation elsewhere in the country at the time might be the deciding factors.

37. Procedure in (and in relation to) Zone Z. The discipline proposed in paragraphs 32 and 33 in respect of Zone Y is regarded as the most severe with which substantial compliance by a population of all ages could be expected. It follows that any attempt to organise communal life in Zone Z would fail and that wholesale clearance of the zone must be undertaken, if sickness and death were not to overtake the great majority of people in it. After 48 hours radioactivity would continue to decay, but at a relatively slower rate. Since people could not remain indefinitely in the zone, the sooner the process of their removal could be started after 48 hours the better.

38. Clearance of Zone Z would be a combined operation. There could be no way of knowing in advance how many people would have to move, but they are likely to be numbered in 100,000's. The broad scope of the operation and its timing together with any related broadcasting of information would have to be dealt with at regional headquarters where the military, police, transport and civil defence welfare interests would be represented. Its detailed planning would have to be organised in sectors each concerned with clearing a particular part of the zone. Its efficient conduct would call for the collaboration of those inside the zone with their rescuers.

39. No one could be sent in to the zone until 48 hours had elapsed; the interval must, however, be used for making preparations to bring all available resources to bear as soon as action became possible. These preparations would be of three main kinds:-

(a) broadcast instructions designed, not merely to sustain morale, but to prepare people in Zone Z to co-operate in their own relief and in particular to convey to those who had their own transport when to move and in what direction to head;

(b) preparation of reception centres in Zone W and beyond and preliminary planning of the clearance movement; and

(c) marshalling transport and organising teams to conduct the clearance operation.

40. Self-help within the zone. The first lift would make use of vehicles already within Zone Z, mainly no doubt private cars, but not excluding motor and pedal cycles and any commercial vehicles whose drivers could get them on the road without going far on foot to collect them. Broadcast instructions would have given these people a broad indication of the time when they should start and of the areas outside Zone X where they might expect to find arrangements made for their reception. It would be stressed in the broadcast advice how important it would be for no one to leave the zone with less than a full load; people would, however, be leaving the zone for a period of some months and would have to bring some luggage with them. Traffic control would be an important police problem. The movement would, however, be one-way and the broadcast instructions could be used to secure some kind of spread-over to ease the situation at the reception end. It would be important to guard against outgoing vehicles impeding transport entering the zone to conduct the second phase of the clearance operation.

41. Some people who had their own transport might not receive the broadcast instructions either because they had no set or because of electricity failure. These people, if not told by neighbours of the instructions given to those with their own transport, would be in the same position as those who have no transport and who were dependent for their evacuation on being fetched.

42. Preparation of reception centres in the free zone. Population density in parts of the country would already be high as a result of the pre-attack evacuation movement. A further population movement into and through these areas would produce acute difficulties of billeting and accommodation as well as of traffic control. The organisation of a large number of reception centres, preferably conveniently sited for further movement by rail, would have to be undertaken before clearance started; people using their own motor transport should be routed through to areas well beyond the areas in which reception centres were set up.

43. Marshalling of evacuation transport and organisation of teams. It would be unsafe, however, to rely on the self-help movement described in paragraph 40 accounting for more than a quarter to a third of the normal population of the zone; allowance must also be made for the effect of the pre-attack evacuation which might have doubled the population in the zone. Wireless broadcasting would need to be used to the fullest extent to explain to the remainder the plans being made to help them; only thus could they be kept in good heart and be convinced of the necessity to remain in their refuges until their turn came. The clearance operation would necessarily be spread over some time and might be delayed for a period as regards the inner areas; people would need to be forcefully reminded that they should not venture into the open except on a direct summons.

44. The first requirement in planning the operation would be for the zone to be broken down into small areas which could be assigned to clearance teams; the wardens post would be the natural unit for this purpose as it is for the control scheme itself. Each team, under the charge of a clearance officer, would have the task of completely clearing its allotted post area, and the movement would take place from as many areas as possible concurrently. During the waiting period, clearance officers would themselves be briefed, study the areas assigned to them and make detailed arrangements with their allotted transport drivers as soon as these reported. The clearance officer would move in to his assigned area in Zone Z as soon as practicable after authority to start the movement was given and establish himself at the warden's post.

45. Conduct of the Clearance Operation. The clearance officer would supervise the operation, acting in conjunction with the post warden. It would be unsafe to rely on the post warden alone who might well be incapacitated. Occupants of houses, who had not moved out, would have been told to signal by way of a window card or other similar device that they were ready to leave when called for. Transport assigned for the operation would report to the clearance officer and be detailed systematically to cover his allotted area. The best procedure would probably be to concentrate on one street at a time. Wardens and street leaders might assist when transport arrived in their own streets by knocking at the doors of all houses displaying the appropriate sign; the aim should be to ensure that no one vehicle spent more than 30 minutes in the zone collecting its load. Persons leaving their homes would be limited to a single suitcase containing their personal effects. When the clearance officer was satisfied that all who wanted to leave had been able to do so, he and the post warden would withdraw. The question of people who did not wish to leave their homes or billets in Zone Z would be a thorny one. They might include people with a degree of protection comfortably above average and a good store of food and water and their own means of transport. In the nature of the case there could be no enforcement, only persuasion, itself based on public education before the event. Clearance of the area would imply that the public services would not be restored for a considerable time; no one would be able to stay indefinitely.

46. The timing of any clearance operation would be a matter for decision at the time. It could not begin before 48 hours had elapsed, but there are obvious psychological and other reasons why it should not start much later. The conditions as regards the air battle might influence the decision.

IX. OPERATION OF THE CONTROL SCHEME

47. The control scheme described in this memorandum will place new and important obligations on regions, on local authority controls, and on the civil defence services, especially the wardens service. The precise manner in which these obligations would be discharged will have to be determined over a period of time as a result of practical trials and experience. This section accordingly attempts only to sketch in very general terms the tasks to be performed and to outline how they may be carried out.

48. Fixing the Zone boundaries. Regions and the central government would receive a forecast and subsequently a picture of fall-out as it was taking place from the monitoring organisation established, inter alia, to provide the information on which the warning system described in Section III would operate. This would be based on readings provided by a network of some 1,500 Royal Observer Corps reporting posts, and it would provide a broad appreciation of the fall-out situation. It would not be sufficiently detailed to settle the precise zone boundaries, but it would provide what was needed at the highest levels of control in the early stages of fall-out. Each zone boundary on the ground would need to be identified as rapidly as possible in terms of the boundaries of a connected chain of wardens post areas determined by the appropriate controls from among the 19,000 or more wardens posts in the country; identification of the posts forming this chain would be a slower process. The procedure for settling the zone category of wardens posts and the resulting fixing of zone boundaries is likely to be on the lines indicated in the succeeding paragraphs.

49. To avoid wardens being exposed to radioactivity while the fall-out was coming down, they would not normally be expected to take dose rate readings until instructed to do so by the appropriate control after the dose rate had begun to decline. The instruction to start taking readings would be given after receipt of the "Blue" message signifying that fall-out was complete. Readings would not necessarily be called for from all posts in a given local authority area immediately, especially if, by sampling, the control discovered high dose rates which made an early decision on the zone category unnecessary. The control (which would have been informed of the time of burst to which to relate its predicted dose rates at 48 hours and, as the information became available, of the rough location of contours) would probably be able to judge which of its posts were critically placed for purposes of settling zone boundaries and would start by collecting readings from those posts. With this information fairly accurate categorisation of wardens post areas should be possible, subject to any necessary checking by higher levels of control especially as regards the junctions of zone boundaries with adjoining control areas. Posts in Zones X and Y would on completion of this process, be notified of their zone category and of the time at which they should set in motion the appropriate release procedure; Zone Z posts would be told to await further information on the plans for clearing the zone; Zone W would be dealt with as described below.

50. Controlling the movement of the W Zone boundary. The determination of the W Zone and the regulation of its effective boundary would be of most importance in the early stages.

After calling for dose rate readings from its posts, the control would have discretion to release immediately post areas where the reading was already below 0.3 r.p.h. provided the post was not flanked by other posts with substantially higher readings. Before any post which abutted on the area of another control was released, consultation with that other control would be essential as a precaution against higher readings just over the boundary and to find out whether or not warning notices were required to be exhibited at the boundary.

51. When a W Zone post was released by its control, the wardens would have two main duties:-

(a) if informed by control that their post had an area not yet released on one flank, to put up "DANGER - FALL-OUT" notices at the boundary of their post area on all roads leading into that area; and

(b) to cancel the fall-out warning for their area and remove any notices which had served their purpose.

52. The release of the rest of Zone W would be based on a system of standard release times - at 0600, 1200, 1800, and 2359 hours (four hourly intervals might be possible). As soon as the initial release of fringe posts had been put in hand, control would calculate for each of its post areas the times at which it expected the dose rate to drop to 0.3 r.p.h. On the basis of this calculation proposed release lines at the standard times would be passed up through the various levels of control for confirmation. Each level, e.g., County or Region, would rectify any inconsistencies between adjoining areas. Provisional release times would be notified by controls to all posts in Zone W as soon as the local proposals had been checked and any necessary modifications made. It would then remain only for posts to take a reading one hour before each standard release time to enable the control to check that the radioactivity was decaying as expected. By this means the outer boundary of the fall-out area would move in systematic fashion across Zone W and warning notices would be exhibited or removed at each stage as appropriate.

53. Controlling the clearance of Zone Z. The planning and conduct of the clearance operation described in Section VIII would involve many agencies. While the local authorities and the wardens service within Zone Z would have a part to play, it seems impracticable for the operation to be controlled by them; this would have to be done from outside the zone. The marshalling and direction of the transport movement on the scale required would be an immense task. There will be evident scope for assistance by the Army in such an operation and considerable responsibilities must, in the nature of the case, fall to the police. The broad scope and timing of any clearance operation would rest with the Regional Commissioner but it may prove desirable to entrust detailed planning and execution of the movement to a specific service. This will be further examined.

54. Role of the Wardens Service. From the references throughout this memorandum to the duties of wardens, it will be evident that a whole range of new duties would be entrusted to them under the scheme. The effect of these new obligations on existing doctrine as regards the functions of the Wardens Service will be dealt with in a subsequent memorandum.

55. Role of the Police. It is also clear that, in addition to the responsibilities falling to local authority controls and the Wardens Service under the scheme, the police will have an important part to play. Co-operation between wardens and police in local post areas would be essential and the police system of communications would be a valuable adjunct for the working of the whole scheme. As a general rule it may be taken that messages relating to the operation of the control scheme passing through the civil defence chain would be repeated through the police network. The requirements of a public control scheme such as is described in this memorandum underline the importance of preserving the existing close association between the police and the Wardens Service.

Home Office, S.W.1.
Scottish Office, Edinburgh, 1.

("Strath Report")

PRIME MINISTER

The Defence Implications of Fall-Out from a Hydrogen Bomb

(D.(55) 17 and 18)

KEY- mis- reported in "news" propag. in 2002!

D.(55) 17 is the report of the group of officials appointed at the end of last year to assess the defence implications of fall-out from a hydrogen bomb. Its broad conclusion is that, although a determined hydrogen bomb attack against this country would cause human and material destruction on an appalling scale, it would be possible to contain its effects and enable the nation to survive if adequate preparations had been made in advance.

2. Many new problems are posed by the hydrogen bomb. The report does no more than outline possible solutions: much more work must be done before it can be firmly decided how far these are practicable and financially acceptable. The study was based on the best scientific information available in this country, which is closely in line with information subsequently released by the United States authorities. But our scientists are still handicapped by lack of information which the United States authorities alone can supply from the work which they have already done. Though they cannot under their legislation disclose information about the actual performance of their weapons or about methods of manufacture, it seems reasonable that the Western Alliance should pool information on methods of defence against hydrogen bomb attack and one would hope that much useful knowledge and experience on this aspect of the problem could be made available without prejudice to United States security requirements. You may wish to mention this point to Admiral Strauss, at your talk with him on Friday afternoon.

3. The group of officials was primarily concerned with the problems of home defence and in particular with the responsibilities of the civil authorities. I understand that the studies on the active defence side mentioned in Section 13 of the Report have already been initiated. But the Defence Committee may like to confirm from the Chiefs of Staff that the Services are making a corresponding study of the

effects of the hydrogen bomb on military organisation and plans.

4. The Home Defence Committee, of which the Chiefs of Staff are members, and the Permanent Secretaries of the Departments directly concerned have considered the report. They endorse its conclusions. D.(55) 18 sets out their main comments but is in no sense a summary of the report.

Mr. Macmillan, when Minister of Defence, had a preliminary informal talk about the report with a few Ministers; but there has not yet been any consultation with the Ministers in charge of civil Departments concerned, except the Home Secretary and the Secretary of State for Scotland. When the Defence Committee has considered the main issues, the Ministerial Committee on Civil Defence can be called to enable Ministers concerned with Departmental planning to express their views on the recommendations which are of special concern to them.

5. Discussion in the Defence Committee should, I think, begin with consideration of the strategic assumptions, which are set out in paragraph 2 of D.(55) 18. The two most important recommendations are these:-

(a) Because the Chiefs of Staff consider that any future war in which the United Kingdom itself was attacked would involve the use of the hydrogen bomb, we should discontinue any home defence preparations which are relevant only to war fought with nothing but conventional or atomic weapons.

(b) Because of the widespread devastation which would inevitably be caused by a hydrogen bomb attack on this country, we should discontinue any plans (e.g. for the building up of industrial war potential) which rest on the assumption that the United Kingdom would be available as a main supply base after the attack.

Endorsement of these assumptions would have important and far-reaching effects. Though I believe them to be correct, there can be no absolute certainty that they would be realised in the event. There is, therefore, a natural temptation to shrink from applying them stringently and to hedge against the possibility that war may take a different form. That, however, would mean that Departments would be asked to plan for two or more different contingencies. Apart from the confusion that this would cause, it is certain that we have not the resources to prepare for more than one. If we attempted to prepare against several contingencies, inadequate provision would be made against any. War planning is in itself an exercise in choosing between various risks: as the resources available for home defence are so limited, they must be concentrated to meet the most likely and most dangerous possibility. A clear lead on this is needed in order to end the present dispersal of effort and to give momentum to the preparations against hydrogen bomb attack.

6. I realise that delicate issues are raised by the assumption that the United Kingdom could not be used as a supply base after the initial attack. For example, a decision by the Board of Trade to dismantle their skeleton organisation of wartime industrial controls would become known to the industrialists who are advising the Board of Trade on these matters. I suggest therefore that, if Ministers approve this assumption, they should do so only for the purpose of enabling detailed studies to be made by Departments; and that Ministers should reserve to themselves the opportunity of considering the implications of those studies before any overt action is taken or any communication is made to outside bodies.

7. In dealing with the report itself, the Committee may find it convenient to go through the summary of conclusions and recommendations on pages 28-31.

The two most difficult and politically sensitive questions of policy are those concerning evacuation and shelter. Dispersal of the population would inevitably cause social and economic dislocation and the report rejects anything like total abandonment of the highly vulnerable areas on that account; it concludes nevertheless that some measure of evacuation would have to be undertaken if casualties on a disastrous scale were to be avoided. The proposal is that priority classes, such as mothers and young children, should be removed to safer areas but that other people should remain at work on a shift system in the high risk areas, moving out at other times to the periphery of the large towns. This would enable the economic life of the country to be maintained and seems the soundest basis on which to work.

A shelter of reasonably simple construction could give security against fall-out and some degree of protection against blast and heat beyond the immediate vicinity of the explosion. But further research is needed, into the most suitable type of construction and into the protection afforded by ordinary houses suitably adapted, before Ministers can be asked to reach a firm decision on the right shelter policy.

The Home Defence Committee suggest (D.(55) 18, paragraph 4) that the Government's eventual plans both on evacuation and on shelter would command wider public support if presented with the authority of an independent committee. But it would be premature to set up such a body until the plans for presentation to it have been more fully elaborated.

8. The Home Defence Committee also recommend (D.(55) 18, paragraph 3) that the Government should not seek to impress the public with the dangers of thermo-nuclear war until they can tell them at the same time what measures of protection can be taken. But public opinion will before long demand the further Government pronouncement forecast at the end of the Statement on Defence, 1955. It will take some time for Departments to examine the full implications of the report for various aspects of home defence and to provide the material for a further statement. This points to the need for giving the necessary impetus to the preparation of plans before Parliament is dissolved.

9. I recommend that the Defence Committee should approve the report by officials (D.(55) 17) as the basis for the preparation of more detailed plans, which should be brought before Ministers for

approval as they become ready. All Departments concerned with war preparations are involved in some way in the report's recommendations and require to use it, as endorsed or modified by Ministers, as background against which to draw up their own particular plans. Because of the pressure of business before the Dissolution, you may think that it will be sufficient if the Cabinet is informed briefly of the Defence Committee's decisions. At Mr. Macmillan's suggestion a copy of the report was sent to all members of the Cabinet, for their personal information, at the end of March.

I also recommend that the Committee should direct that the revision of war plans should be based on the strategic assumptions given by the Home Defence Committee in paragraph 2 of D.(55) 18 and should take account of the other points made in that note.

21ST APRIL, 1955

TOP SECRET

MINISTRY OF DEFENCE, S.W.1.

PRIME MINISTER

I am glad to have your general approval of my proposals for studying the affect of "fall-out" on our war plans.

2. I am appointing the following to carry out the preliminary study described in paragraph (3) of my minute:-

Mr. W. Strath - Cabinet Office
General Brownjohn - Representing the Chiefs of Staff
Sir Richard Powell - Deputy Secretary, Ministry of Defence
Sir Frederick Brundrett - Scientific Adviser to the Ministry of Defence
General Kirkman)
Mr. P. Allen) - Home Office

This group will be under the chairmanship of Mr. Strath, who is working in the Cabinet Office under the personal direction of Sir Norman Brook on the inter-departmental aspects of war plans. On the choice of the other members of the group I have had Sir Norman Brook's advice.

Arrangements will be made to enable this group to obtain advice, as required, from the Chairman of the Joint Intelligence Committee, the Economic Adviser to the Treasury and the atomic scientists in the Atomic Energy Authority.

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TOP SECRET

The military consequences of "fall-out" will be studied by the Chiefs of Staff themselves; but General Brownjohn will provide the link between them and Mr. Strath's group.

3. As decided this afternoon before the Cabinet, I am arranging to send my paper (C(54)389) to members of the Cabinet. It will go with your paper on Tube Alloys and to the same limited circulation.

HAROLD MACMILLAN

<u>13th December, 1954</u>

"Keep me informed please.
W.S.C.
14/12."

14/12.

E.R.

Copies to Sir N. Brook
Foreign Sec
Lord President
Home Sec

Sec
COS
D/Sec
Sir F. Brundrett

DRAFT

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Arrangements will be made to enable this group to obtain have advice, as required, from the Chairman of the Joint Intelligence Committee, the Economic Adviser to the Treasury and the atomic scientists in the Atomic Energy Authority.

The military consequences of "fall-out" will be studied by the Chiefs of Staff themselves; but General Brownjohn will provide the link between them and Mr. Strath's group.

3. I note your approval of my suggestion that members of the Cabinet should be told of what is afoot. I am preparing a short paper, as you suggested; and I will let you know when this is ready, so that you may decide when the question should be raised in Cabinet.

DECEMBER 1954

10, Downing Street,
Whitehall.

Top Secret December 12, 1854.

Dear Hanna

I return to you the Minister of

7-

Defence's minute of December 10 on which you will see the Prime Minister's manuscript comments. Would you please return it to us again after perusal?

Campbell informed

Yours sincerely

A.A.D. Montague Browne

W.N. Hanna, Esq., M.V.O.,
Ministry of Defence.

E.R.

TOP SECRET

MINISTER OF DEFENCE

At the meeting in the Foreign Secretary's Room on Thursday, it was agreed that a small group of senior officials should now be appointed to study the implications, from the point of view of defence policy, of the latest information about "fall-out" from a hydrogen bomb.

I have discussed the composition of this group with your advisers. We agree in recommending to you that it should be composed as follows:-

Mr. Strath (Chairman)
General Brownjohn
Sir Richard Powell
Sir Frederick Brundrett
General Kirkman

They would have power to co-opt, as required, Sir Robert Hall (Economic Adviser to the Treasury) and Mr. Patrick Dean (Foreign Office) and a scientist to be nominated by the Chairman of the Atomic Energy Authority.

If you approve this plan, Mr. Strath will get to work on this at once.

Norman Brook.

11TH DECEMBER, 1954

approved – H.M.
13. 12. 54

Mr Campbell informed

(313) Dd.D922/W:34369 20,000 1/54 JC&S Gp698

MINISTRY OF DEFENCE, S.W.1.

PRIME MINISTER

Copy No 3

I attach a draft of a paper on which I have been working, with the help of the atomic scientists, on the "fall-out" effects of a hydrogen bomb.

I am having a talk about this today with the Ministers immediately concerned - Foreign Secretary, Lord President and Home Secretary.

This discussion may help me to improve this draft and perhaps put forward more precise proposals which, if you agree, could then be discussed by the Defence Committee.

HAROLD MACMILLAN

9th December, 1954

E.R.

DRAFT

TOP SECRET

PRIME MINISTER

I have now discussed with the Foreign Secretary, Lord President and Home Secretary the draft paper on the "fall-out" effects of a hydrogen bomb, which I sent to you with my minute of December 9. The following points emerged from our talk:-

(1) It would be better that these questions should not be raised formally with the United States Government until after Congress has approved the proposed new agreement for the exchange of technical information about atomic energy development between the United States and ourselves.

Two points could however be cleared informally with the Americans while they are in Paris for the forthcoming meeting of the North Atlantic Council. First, the Foreign Secretary could ask Dulles for an assurance that the United States ~~Government~~ would not make any dramatic ~~official~~ Government announcement on "fall-out" without giving us advance warning that it is to be made. Secondly, I could ask Charles Wilson whether the Administration intend to continue to educate their public on "fall-out" effects along the lines which they are now following. Broadly, these are to spread information about the effects, while withholding knowledge of the wide area over which those effects are felt.

(2) We cannot work out what adjustments have to be made in our plans, on account of "fall-out", before the time comes to publish the Defence White Paper in February. In that paper therefore we must outline plans which take account of the atomic bomb and of the

/explosive

(513) Dd.D922/W:34389 20,000 1/54 JC&S Gp689

E.R.

explosive effect of a hydrogen bomb, but do not take full account of "fall-out". We can cover ourselves - and prepare for the further disclosures which will come later - by stating in the paper that all the effects of the hydrogen bomb have not yet been fully measured. This means that the paper will describe an intermediate phase in our plans. But this is reasonable, since plans are at present in an evolutionary stage.

(3) We must begin to adjust the war plans of all Departments to take account of "fall-out". But, ~~as~~ since we do not propose that any official announcement about the nature of "fall-out" should be made immediately, we cannot yet disseminate knowledge of it throughout the wide circle of Whitehall officials who would need that information if it were to be taken into account in detailed planning. As a first step, therefore, we think that a small group of officials should be set to work to prepare a report, for consideration by Ministers, on the broad consequences of "fall-out" on our war plans as a whole. This group would consist of representatives of the Chiefs of Staff, Ministry of Defence, Cabinet Office and Home Office.

If you are in general agreement with these proposals, I doubt if the Defence Committee need consider at this stage a paper on the lines of the draft which I previously sent to you. Within the narrow limits suggested above the preparatory work could go forward without a preliminary discussion by the Defence Committee.

But I do think that members of the Cabinet should have in their minds a general picture of the problems with which "fall-out" confronts us, and should know what steps we are taking to study these and to keep in contact with the Americans on them. ~~It seems to me, that for this purpose, it~~ ~~I think the best way would be for~~ ~~would suffice if the Lord President and I made~~ oral ~~explanations~~ statement to the Cabinet on some suitable occasion. [~~I should be glad if the Service Ministers were present when this was done.~~]

~~Perhaps the~~

?

I think the ~~best way of~~ simplest course wd. be for ~~the~~ Lord P. & myself to make - - -)

R.

TOP SECRET

"FALL - OUT"

1. The grim effects of "fall-out", added to the destructive power of the thermo-nuclear weapon, make global war less likely. The possibility of mutual annihilation is too great.

2. In the next three or four years it is even less likely that Russia will provoke war, while she is unable to strike decisively against the U.S.A.

3. But in a war the United Kingdom - the nerve centre of European resistance - would be extremely vulnerable to nuclear attack. There is not in sight any air defence system which could protect us effectively.

4. In short, possession by the West of the nuclear weapon is at present a real deterrent. Overwhelming and immediate retaliation with it is our only reliable defence.

5. To maintain the strength of the deterrent must be the heart of our defence policy. The maintenance of the N.A.T.O. shield is an integral part of this strategy.

6. But the cold war will go on. Indeed the temptation for the Communists to pursue their aims by limited and local aggressions - calculated not to trigger off total war - may even increase, as the outcome of a major adventure becomes more imponderable. We must be ready to play our part in countering moves of this sort.

7. It must, therefore, continue to be the aim of our foreign policy to make the Atlantic Alliance secure and to consolidate the will of the free world elsewhere to resist Communist subversion and infiltration.

8. To do this effectively we must also show that the free world can provide a better life. This we cannot do unless the economies of the West are strong and the backward areas of the world are helped to develop their resources.

9. These combined aims are bound to put a severe strain on our own resources. It is essential to strike a proper balance.

What do we do?

10. The latest scientific appreciation of the nuclear weapon

/demands

F.R.

demands a fresh reappraisal of our defence plans, both military and civil.

11. For this purpose we need a new appreciation by the Chiefs-of-Staff of the conditions in which a nuclear war would be fought, and of the time when they expect the threat of nuclear war to be greatest.

12. Thereafter it will be necessary to consider how our existing defence plans need to be modified to meet the new conditions and whether there are any which we can relax without damage to the effectiveness of the deterrent.

13. Under nuclear bombardment we can no longer count on the United Kingdom being able to function as a main supply base. The implications of this need profound study.

14. The widespread damage and immobilisation caused by "fall-out" call for a radical reshaping of our plans for the defence of the home front. New problems of an unprecedented kind are created for the protection of the population - for shelter and evacuation plans. The role and organisation of the Civil Defence services need radical overhaul. How far should they be geared to their normal tasks of fire fighting and rescue and how far to relief and decontamination measures? The part which the military forces may have to play in support of the Civil Authorities needs to be determined. The effects of radioactive contamination create vast and novel problems for the medical services and for agriculture. And finally there are the problems of the survival period.

15. It is evident that civil defence in the broadest sense of the term must command a higher priority in defence planning than it has so far received.

16. Public Presentation

There is the difficult problem of educating public opinion in the implications of "fall-out". At home we must secure understanding for the new direction that must be taken in our defence planning in consequence of this latest threat, and this must be done without undermining public confidence. A somewhat similar problem faces the United States and our other Allies in N.A.T.O. Unless the form and the timing of the solution as proposed by each Government are concerted beforehand, the morale of the Alliance may be shaken.

17. Next Steps

(i) What should we now do to bring about adjustments of our defence plans?

Before our detailed defence plans can be revised Departments responsible for planning must be given appropriate guidance about the implications of nuclear warfare. Before this is done it is suggested that a small body of officials should quickly review the field likely to be principally affected, prepare a plan of work, and indicate the nature of the guidance which planning Departments will require. This body should be strictly limited in number and might comprise senior representatives of the Chiefs-of-Staff, Ministry of Defence, Home Office, and of the Cabinet Office (Central War Plans Secretariat). There should be available to them scientific assistance. The body might also include a representative of the Foreign Office and Sir Robert Hall (the Government's Chief Economic Adviser) on a personal basis.

(ii) What should we say to the public?

In the first instance early consultation with the Americans would be desirable about the political problems of presenting to the public the implications of the new threat. It is suggested that this might most effectively be done by a visit to the United States by you accompanied by the Chief of the Imperial General Staff. It might be possible to prepare the ground for such a visit in discussion with the United States representatives to the forthcoming Ministerial Council of N.A.T.O.

It will not be possible for an extensive review of our defence plans to be completed by the time the White Paper on Defence is published in February, but the facts about hydrogen bombs, including "fall-out" are already fairly widely known and it will not be possible to postpone for long some announcement of our policy for dealing with this menace.

(W. STRATH)

8th December 1954

TOP SECRET

P.S. TO MINISTER OF DEFENCE

FALL - OUT

Sir Norman Brook yesterday sent to the Minister of Defence a draft memorandum on "fall-out".

Sir Frederick Brundrett has called my attention to an error in the Annex which requires correction. The penultimate sentence of the paragraph at the top of page 5 of the Annex should read as follows: "A thickness of 12 inches of earth would reduce the radiation dosage rate by a factor of about 15". I should be grateful if you would make the necessary correction in the paper which your Minister has.

(W. STRATH)

30th November 1954

F.R.

Minister.

Do you intend to do anything about this at present? I think we ought to let Sir N. Brook have some indication of your reactions to his minute.

TOP SECRET

MINISTER OF DEFENCE

On 8th November the Chiefs of Staff discussed with the atomic scientists some of the implications of the latest information about "fall out" from the explosion of a thermo-nuclear bomb. Sir Harold Parker and I were present at this meeting.

It was then agreed:-

(i) that this was of such importance to all our war plans that no further time should be lost in bringing it formally to the notice of the Ministers immediately concerned;

(ii) that the problem should, in the first instance, be submitted to a limited group of Ministers, viz., the Prime Minister, Foreign Secretary, Lord President, Minister of Defence and Home Secretary;

(iii) that, as Civil Departments and scientists were concerned as well as the Chiefs of Staff, it would be convenient that (if you are agreeable) you should circulate a paper which would form the basis for discussion in this limited circle.

2. The attached paper has now been prepared for this purpose. It takes the form of a covering note by yourself and a scientific appendix. Both parts of the draft have been prepared in consultation with your military and scientific advisers.

3. I hope you will agree that something on these lines should be circulated, without delay, for discussion by the Ministers mentioned in sub-paragraph~~s~~ (ii) ~~(i), (iii)~~ above. I think it very desirable that these Ministers should have the facts in their minds before they become involved in the discussion of general defence problems - whether this takes place publicly in the Debate on the Address or in private discussions with members of the Opposition.

If/

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E.R.

If you agree, I suggest that you should send a copy of the attached memorandum (with any amendments which you wish to make) to the Prime Minister suggesting that it should form the basis for an early discussion with the other Ministers mentioned above.

Norman Brook.

29TH NOVEMBER, 1954

(813) Dd.D822/W:34989 20,000 1/54 JC&S Gp869

E.R.

TOP SECRET

FALL-OUT

Draft Memorandum by the Minister of Defence

I attach a note on the effects of the explosion of a thermo-nuclear bomb. Its main purpose is to describe the conditions created by fall-out - the radio-active contamination which is caused when a bomb bursts at or near ground level. The effects of other forms of energy released by a thermo-nuclear explosion - blast and heat - are outlined briefly.

2. This analysis is founded on the latest scientific information we have. It accords with all that we have been able to find out about the effects of the experiments by the United States in the Pacific and elsewhere. It is also supported by a similar analysis carried out by the Canadians. We would naturally like to have consultation with the United States in order to confirm that the conclusions reached by our scientists are compatible with those to which American scientists have come. From the varied contacts which have taken place with the Americans, we have no reasons to suppose that they would dissent on any point of substance from the analysis here given. But we cannot be certain of this until our formal request to the Department of Defence for co-operation and consultation in this field has been submitted to Congress for approval as required by the 1954 Atomic Energy Act. I understand that the United States Administration hope to lay the proposed Agreement before Congress in January. In such event the consequent constitutional processes should be completed in time to permit of joint consultation with us early next spring.

3. This means that the United States Authorities will continue to be debarred from entering into the discussions, which they as well as we agree are necessary, until after the defence estimates are presented to Parliament for 1955/56. Regrettable as this is, we should, I think, consider whether there are not certain aspects on which an approach should be made in the meantime. We need, for example, to discuss with them the revised strategic

/concept

concept of the Chiefs of Staff and the implications which this has for Allied defence policy. Even more urgent is the need to consult with them on the political problems with which they as well as we are faced in presenting to the public the changes which the advent of the hydrogen bomb imposes on our respective preparations for defence.

4. There are indications that the United States Government are now considering the political implications of the hydrogen bomb for their home front. But we cannot be sure that they will consult us before making any public announcement about its impact on their defence plans, and, if they should announce their policy without prior consultation with us, we must be able to show that we are not unprepared for these problems in our new defence policy. Moreover, by initiating discussions with the Americans on the aspects which I have suggested, we should avoid giving the impression that the purpose of our approach is to obtain information about atomic energy, which they consider themselves unable to give us without the approval of Congress.

5. Valuable though United States confirmation of our conclusions about fall-out would be, our scientists are confident that the margin of possible error in the attached analysis is not wide enough to invalidate its substance. Moreover, the significance of fall-out for our defence planning would not be materially affected even if the consequences were later found to be somewhat less bleak than they appear now. There are no grounds, therefore, for deferring the necessary re-orientation of our planning until we can check our own conclusions with the Americans.

6. It is, I think, evident that this new information must have a revolutionary effect over a wide range of our war plans, both military and civil. Thought is already being given to its implications by the limited circle of Ministers and officials to whom this scientific appreciation is known. But we cannot ensure that all our preparations will be properly adjusted to allow for this new factor without widening the limit within which knowledge

/of the

E.R.

of the new implications has so far been confined. Unless this is arranged, much of our planning is bound to get out of gear.

7. If this is done, however, we must accept some risk that people may come to know quite soon that the Government are planning on this new hypothesis. Admittedly, almost all the conclusions in the attached note could be reached by diagnosis of material which has been published. But much of the present indifference of the public would vanish if they found that the Government had adopted this basis for their defence plans.

8. I therefore propose that we should now consider:-

(a) The extent to which it is desirable to issue guidance on the implications of fall-out to Departments concerned with defence preparations.

(b) The manner in which the implications of fall-out for our defence policy should be presented to the public, bearing in mind that the facts of this subject are in large measure already available to them and that the radical changes in Government plans require to take account of fall-out cannot long be concealed from the public once they are applied to our defence preparations.

(c) The form and timing of an approach to the United States Government on problems raised in this paper. The emphasis on the initial discussions should, I suggest, be on the common political problems which are raised for the Americans as well as ourselves by the development of thermo-nuclear weapons, and on the importance of harmonising the presentation to the public of the changes which we must each make in our defence policy. It would also be valuable to exchange views with the Americans, initially perhaps on the Chiefs of Staff level, on the implications of the latest developments for the strategic policy of the Western alliance.

NOVEMBER 1954

E.R.

TOP SECRET

ANNEX

The explosion of a hydrogen bomb releases energy in three forms - blast, heat and nuclear radiation. Their relative importance depends on the distance of the bomb from the surface at the moment of explosion. Broadly speaking, the effects of blast and heat are comparatively local in all cases, whereas those of radiation may be very widespread.

2. Size of the Bomb. There is no technical limitation to the yield of this weapon. The analysis which follows is related throughout to a 10-megaton bomb (10 M.T.). The highest yield achieved in the United States experiments to date is 30 M.T. The area affected by a bomb of this yield would be about 45% greater than in the case we are considering.

3. Blast and Heat. Blast and heat are more intense from an air burst than from a ground burst. In dull weather damage from the heat wave is somewhat less extensive than in clear air. The blast and heat resulting from the explosion of a 10 M.T. bomb would cause destruction on about the following scale:-

	Air Burst 10 M.T. at 20,000 feet (Radius in miles)	Ground Burst 10 M.T. (Radius in miles)
(a) Surface devastation to ordinary brick houses.	7½	5½
(b) Devastation to facilities and tunnels below ground.	Nil	⅓ mile in radius and depth
(c) Major structural damage to brick houses.	9	6¾
(d) Surface damage by fire on ordinary day.	8-12	5-9

4. <u>Radiation</u>. The initial radiation occurring within a few seconds of detonation of a bomb, whether air burst or ground burst, is probably confined within a radius of three or four miles. The area thus affected is, therefore, in any case devastated by heat and blast.

The residual radiation occurring as an after-effect of the explosion varies very greatly in its effects, according to the point of burst.

If the bomb bursts too high for the fire ball to reach ground level, the bulk of the radio-active materials are carried into suspension in the upper atmosphere. They are then so dispersed that they have no serious local effects when they eventually settle out.

But if the bomb bursts at or near the ground,* quantities of much heavier radio-active particles are carried for a while by the winds that blow in differing directions at different levels. The pattern of precipitation is irregular, varying with the speed and direction of the air currents in the area, but a high proportion of the fall-out occurs from very high levels where the winds are more constant in direction and speed. This tends to elongate the area of contamination in the direction of the winds there prevailing.

5. <u>Effects of radiation on life</u>. No medical means of curing or even curbing the effects of radiation on human beings are yet known. On human beings the effects are cumulative over a considerable period, becoming lethal when a certain dosage has been absorbed. In the Marshall Islands natives on an atoll 110 miles from the explosion received about one-third of the lethal dose: Americans who remained in huts 150 miles downwind received over a tenth of the lethal dose. Both these groups were 20 miles off the main line of fall-out.

*The effects of an explosion on or under the sea are, broadly, intermediate between those of a ground burst and of an air burst bomb.

Symptoms of radiation sickness may not show for some days, or even weeks. But about one-fifth of the lethal dose produces temporary sickness, with increasing disability as absorption increases beyond this point.

On animals the direct effects are similar. (In the Marshall Islands all animal life was extinguished on an atoll 110 miles from the explosion.) Moreover, one of the products of the explosion is radio-active strontium, which has an exceedingly low rate of decay. If it gains access to the body, it is deposited in the bones like calcium. Cattle which escaped other effects of radiation would become casualties if they ate grass, even in small quantities, which was contaminated in this way. Any milk they produced before they died would be unsafe for human consumption. Owing to the difficulty of arranging food and cover, most of the sheep and cattle in the contaminated area would be wiped out.

All growing crops subjected to serious contamination would have to be destroyed, though root crops might be safe if they could be harvested quickly without being infected by surface contamination in the process. Similarly, crops like beans might be safe, provided the pods could be removed without contaminating the beans themselves. Further investigation of the implications for agriculture is necessary, but it is certain that it would not be safe to use land contaminated with strontium for at least a year, and possibly for several years.

Radiation does not in general affect inert matter. Consequently, foodstuffs outside the inner lethal zone would almost certainly not be impaired, provided they were under cover and therefore not directly contaminated. It would be necessary to decontaminate the coverings to ensure the safety of people handling them and to prevent contamination of the contents.

6. <u>Area of contamination</u>. The superficial area which is contaminated will not vary much in size, but its shape will depend on the prevailing wind structure. The fall-out from a single ground burst 10 M.T. bomb would cover an area of 5,000 to 6,000 square miles.

7. <u>Persistence</u>. The radio-activity will decay with the lapse of time. The rate of decay is very rapid in the early stages, but flattens out thereafter and may persist for a long time in regions of initial high contamination.

8. <u>Degree of Contamination</u>. In general, the density of contamination will diminish as the distance from the point of burst increases, but the shape of the contour indicating any particular rate of contamination will depend on the prevailing wind structure.

There will be an inner zone of approximately 270 square miles in area (larger than Middlesex), in which radiation will be so powerful that all life will be extinguished, whether in the open or in houses. Because of the persistence of the radio-active contamination in this inner zone, general relief measures would be virtually impossible for some weeks, and possibly months. People in specially deep shelters with their own supply of uncontaminated food and water would have some chance of survival, provided they were not entombed by other effects of the explosion. Even so, for at least a week it would not be safe for them to attempt to emerge and leave the area. Fires in this area would have to be left to burn themselves out.

Outside this central zone, the density of radiation will diminish progressively with distance from the point of burst, but the rate of diminution in any particular direction depends on the prevailing wind. Within an area of about 3,000 miles, which with a steady 20 knot wind would be 170 miles long in the direction of the wind and over 20 miles wide in places, exposure in the open on the first day might easily be fatal. Rescue operations could commence on the outer fringes on the second day and thereafter proceed with gathering momentum but the greater part of the area would be immobilised for several days. Survival in this area depends on cover. The efficiency of the cover depends on the weight of the screening material. A thickness of 12 inches of earth would reduce the radiation dosage rate by a factor of about 15. Suitably screened shelter in an ordinary well-bricked house can reduce the dosage rate by a factor as high as 20.

There will be an outer area of 2 - 3,000 square miles in which there is a danger of radiation sickness if no precautions are taken. In general, it would be sufficient for people to stay indoors for about 12 hours after the onset of contamination. As this depends on the speed of the wind, fall-out will not occur until 8-24 hours after the burst, and it might therefore be possible to move some people out of the main path which fall-out was expected to follow, should such a step be considered desirable.

9. It will be clear from the above that, if there is more than one burst within a period of days, the wind structure might be such as to cause an overlapping of the contaminated areas. In such case, there might well be isolated pockets of high density contamination at considerable distances from the explosions.

T 62/57

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UNITED KINGDOM ATOMIC ENERGY AUTHORITY

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

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REPORT No. T 62/57

OPERATION BUFFALO

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RMCS Date 29.5.86

Air and Ground Shock Measurements Group

Group Leader - N. S. Thumpston

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~~GUARD~~

A.W.R.E.,
Aldermaston, Berks.

November, 1957

SECRET
GUARD

United Kingdom Atomic Energy Authority

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT No. T62/57

OPERATION BUFFALO

Air and Ground Shock Measurements Group

Group Leader - N. S. Thumpston

Summary

At Operation Buffalo measurements were made of the hydrostatic pressure and pressure/time variation of the air shock wave along the main instrument lane using three types of gauge, and measurements of the drag pressure using a fourth type of gauge.

This report gives a brief description of the recording methods used and graphs of the peak positive pressure, duration and time of arrival of the air shock plotted against distance from Ground Zero.

In Rounds 1, 3 and 4 precursor-like waveforms were obtained and in these cases the records obtained are reproduced in the text.

From considerations of the pressure/distance data the Total Energy Yields of the weapons are estimated to be:-

Round 1	-	17 kilotons
Round 2	-	1 kiloton
Round 3	-	$2\frac{1}{2}$ kilotons
Round 4	-	15 kilotons

The other activities of the Group included measurements of ground shock and determination of blast pressures from the observations on smoke rocket trails. These activities are reported separately.

Received on 6th September, 1957.

Table of Contents

List of Figures

1. Introduction

The Air and Ground Shock Measurements Group (AG Group) at Operation Buffalo totalled 19 members. Fifteen, including the Group Leader and his Deputy, came from the Foulness Division of the Atomic Weapons Research Establishment and the other four were from the staff of the Suffield Experimental Establishment of the National Defence Research Board, Canada.

2. Object

The main task of the AG Group was the measurement of blast pressure and ground shock variables from which the performance of the weapons could be assessed and from which basic data on the effects of atomic weapons could be obtained.

The seven commitments of the Group were as follows:-

AG 1. To measure the hydrostatic pressure and pressure/time variation in the air shock wave, along the main instrument lane over an appropriate range of distances.

AG 2. To estimate the blast equivalence of each weapon from the velocity of the shock wave by a direct timing method.

AG 3. To observe precursor phenomena on appropriate Rounds (1, 3 and 4). This comprised the direct measurement of drag pressure and temperature variations in the air.

AG 4. To measure on Rounds 1 and 2 the variation with time of ground particle velocity and acceleration.

AG 5. and 6. To measure, for the Structures, Ordnance and other Target Response Groups, the pressure/time variation of air blast in and around structures and Service vehicles.

AG 7. To measure the maximum pressure in the free air shock wave from observations on smoke rocket trails.

Serials AG 1 to 6 were carried out by United Kingdom members of the Group and Serial AG 7 by the Canadian members.

This report deals with the observations that were made on Serials AG 1 and part of AG 3 (the drag pressure measurements). The remaining work will be reported separately.

3. Apparatus and Method

3.1 Blast Pressure Measurements

Two types of mechanical and one type of electronic gauge were used for blast pressure measurements. A photograph of a gauge site is shown in Figure 1.

3.1.1 Diaphragm Gauges

The mechanical diaphragm gauge records the deflection of a thin metal diaphragm by scribing a cylindrical lens on a moving celluloid strip with a shaped stylus, thereby giving directly a small pressure/time trace which could be magnified to convenient dimensions. The gauges used on Operation Buffalo were similar to those deployed on previous weapon trials with two modifications, both arising from trials experience. These were:-

(a) The inclusion of frequency-controlled mains-driven motors, coupled to a marker, so that a time trace was included on the record. This overcame the doubts of previous trials as to whether or not the motor driving the celluloid strip had maintained correct speed;

(b) the addition, over the diaphragm, of a cover in which there was a predetermined leak. By making the leak of suitable size the rate of build up of shock pressure on the diaphragm can be limited, to avoid the initial overshoot which had marred previous records, without introducing significant inaccurancies into the pressure/time variations received by the diaphragm. The size of the hole to provide this controlled leak was determined experimentally from field firings and shock tube work in the United Kingdom, and is critical.

At Maralinga, Mr. K. Darby was responsible for diaphragm gauges. The field requirements for the gauges were small. Each gauge required a mounting post and a cable connection to the rear of the instrument line for a time sequence starting signal at -30 sec, and for electrical power supply.

To avoid total loss of records from possible electrical generator failure, half of the gauges were connected to one generator and the remainder to a second generator.

3.1.2 Collapsible Tubes

The collapsible tubes measure peak pressure only, the principle being to relate the extent to which empty toothpaste tubes are crushed to the intensity of the blast wave to which they are subjected. Collapsible tubes have been used on all previous British trials.

The toothpaste tubes used on Operation Buffalo were made of aluminium and were smaller than those previously used, being only 8 cm long. They were purchased open-ended and were carefully folded in the United Kingdom to ensure uniformity of volume, after being preformed to a roughly rectangular shape to improve their sensitivity. The tubes were used in sets of nine in a hatchet-shaped baffle of new design (Figure 1). Two baffles were set out at each gauge station.

To measure the volume of the collapsed tubes after firing a water chain balance was made. The collapsed tubes were sealed and the buoyant tubes balanced under water against a length of submerged chain.

Mr. G. Harwood was the member of the Group responsible for tubes at Maralinga. Field requirements were small, being only two posts at each site for mounting the baffles.

Use of these tubes provides a simple method of measuring pressure but it must be noted that their behaviour varies with the shape of the wave to which they are subjected. The calibration from shock tube to Friedlander wave shape does not apply if the incident wave is multiple peaked.

3.1.3 Frequency Modulated Tape Recorder and Variable Inductance Gauge

The electronic gauge and recording assembly used on Operation Buffalo represented a new method of recording pressure/time relationships. The pressure sensitive head is a commercial variable inductance gauge mounted on an 8 in. long hatchet shaped baffle (Figure 1). The inductance forms part of an oscillatory circuit, variations of the frequency of which are recorded on magnetic tape. This system of recording has the virtue of being insensitive to radiation.

The frequency modulated tape recorder (FMT) was developed after experimental adaption of commercial components and was mounted on shock absorbers in a domed-top cylindrical container designed to withstand the expected pressures and ground shock (Figure 2). The recorder was mounted a few feet from the gauge element, thereby considerably reducing the cabling effort.

After the firings the tapes were collected and played back in the laboratory, the signal being displayed on a cathode ray oscillograph and photographed to give a permanent record. By playing the tape through slowly, interesting parts of the records could be reproduced with an extended time scale.

The FMT recording system was developed by the Deputy Group Leader, Mr. H. G. MacPherson, and was operated at Maralinga by Messrs. MacPherson, Turner and Pottinger. Field requirements for the FMT system were a gauge stand to carry the pressure head and a nearby hole for the FMT recorder in its container, the diameter of which was about 3 ft. In forward sites the shock-proof container was covered with sandbags. Each FMT site was coupled by a common cable to the rear of the instrument base to receive the initiating time sequence at -30 sec.

3.1.4 Drag Gauge

This gauge was used on Rounds 1, 3 and 4. It was designed to measure the stagnation pressure associated with the airflow behind the shock front and to assess the effect of sand in this airflow. The gauge (Figure 4) consists of a hollow cylindrical body, open at the front end, containing two recording pistons. The forward piston has a hole through which air flows to equalize the pressure on the front and back. This piston is intended not to react to the stagnation pressure but only to the direct impact of sand particles, thus recording the "sand pressure". The rear piston is shielded from the sand; its purpose is to record the difference between atmospheric and stagnation pressures. The pistons move against beryllium-copper springs on which are attached metal foil strain gauges. These strain gauges are connected to form a Wheatstone Bridge; the out-of-balance current, proportional to the pressure on the pistons, is recorded on photographic paper by a 6-channel recording mirror galvanometer.

The drag gauge was developed by Mr. G. Warren, who was also responsible for its use at Maralinga.

The gauges were mounted at two heights on heavy girders concreted into the ground in the region where a precursor was expected. They were connected, with 6-core cable, to the recorders (Figure 3) housed in a steel shelter about 4000 ft from Ground Zero.

3.2 Layout Arrangements at Maralinga

The blast pressure instruments were mounted on a series of prepared sites on the AG instrument lane. The lane was on the East side of the approach road running North to Ground Zero excepting the fore-end of the lane on Round 2, which was adjacent to the road on the West side. The lanes were 60 ft wide, with roughly graded surfaces. The gauge posts were set in concrete blocks, about 2 ft deep and 4 ft wide and of a length depending on the number of posts. The gauges were mounted with the FMT gauge nearest the road and the diaphragm gauge furthest from the road (see Figure 1).

Cable runs were made down each side of the lane, the power cable being kept separate from the time sequence and signal cable. Prior to firing, cables back to about the 10 p.s.i. level were buried.

When mounted on the posts the gauges were orientated so that the hatchet-shaped baffles were edge-on towards Ground Zero.

For the firings at One Tree (Round 1), Marcoo (Round 2) and Breakaway (Round 4), blast gauge sites were set out at distances corresponding to the anticipated pressure levels: 100, 72, 51, 37, 27, 20, 15, 11, 8.8, 6.8, 5.3, 4.3, 3.4, 2.7, 2.2, p.s.i. Two tube baffles were used at each site, plus one FMT gauge from 51 p.s.i. downwards and one diaphragm gauge from 37 p.s.i. downwards.

For Round 3, the air drop at Kite, a similar arrangement had been planned but included extra forward gauge sites to allow for inaccuracy of drop. Owing to a late change in the weapon to be dropped the gauge sites for Kite were altered at Maralinga, some of the existing sites being used and some new ones prepared. On this Round also, the baffles were mounted horizontally.

A schedule of sites is set out in Tables 2 to 4 (pp. 11 and 13).

As previously indicated, the drag gauges were used on Rounds 1, 3 and 4 and were mounted in pairs on heavy girders (Figure 3). A schedule of sites is set out in Table 5 (p. 14).

4. Results

4.1 Pressure Data, Including Duration of Positive Phase and Time of Arrival of Shock Front

A very high percentage of records was obtained and recovered, yielding extremely good results.

The pressure data are set out in Tables 2 to 4. On Rounds 1, 3 and 4 a precursor was developed, giving rise to irregular multipeaked wave shapes above a certain pressure level. Where this happened the letter "P" is written against the quoted "peak pressure" in the table and the actual FMT record is reproduced later in the report. To illustrate the smooth FMT records, other Figures, e.g., 9, 10, 15, 16, 18 and 24, show the records from sites beyond the precursor region. Where the actual record has not been reproduced the wave shape was a single peak as in Figure 18.

The wave shapes from the diaphragm gauge resembled those of the FMT gauge in general form only; the details were lacking. But the results from the diaphragm gauges indicated that the precursor may have persisted to a slightly lower pressure than that indicated by the FMT gauges.

In the precursor region results from the collapsible tubes were very erratic, as might be expected. The results from the tubes on Round 1 were markedly lower than those obtained from the FMT or diaphragm gauges; no explanation can be seen for this.

The results are also set out in 16 graphs, Figures 25 to 40. These are for each round:-

(a) Pressure/distance curve based on the FMT results.

(b) Pressure/distance curve for diaphragm gauge and tube results showing fit to FMT curve. Only points outside the precursor region have been plotted. Reference to the table shows the irregularity of mechanical gauge results within the precursor region.

(c) Duration/distance curve based on FMT results.

(d) Time of arrival/distance curve based on FMT results.

For Rounds 1 and 4 the pressure/distance curves were fitted to give the best agreement with the AWRE "Height of Burst" data (see Figure 41). An approximate yield figure was obtained by inspection, and the equation to the pressure/distance curve was calculated from the "Height of Burst" data and fitted to the Buffalo results by choice of a suitable scaling factor to give the best "least squares" fit.

For Rounds 1, 3 and 4, the points on the pressure/distance curve are joined by a firm line only where the shape of the pressure pulse was normal.

4.2 Drag Gauge Results

5 The drag gauge results are given in Table 5 (p. 14). No results are shown for the front piston of the gauge because in no case was any significant thrust from the sand particles recorded. No significant quantity of sand was collected inside the gauges either.

5. Conclusions

5.1 Pressure Measurements - Weapon Yields

From the pressure/distance data estimates were made of the TNT charge which, fired in the same conditions, would give the same pressure/distance relationship; this was done by comparing the results with the British "Height of Burst" curves (Figure 41) which are drawn from pressure measurements in small charge firings.

The equations fitted to the pressure/distance data were of the form:-

$$P = \frac{as}{R} + \frac{bs^2}{R^2} + \frac{cs^3}{R^3}$$

P being peak pressure and R being distance. The constants a, b and c were derived from the height of burst curves and s was fitted by least squares.

To convert the equivalent TNT charge to "Total Energy" it is necessary to know what fraction of the total energy goes into blast. The figure usually accepted is 0.45 but this is believed to be applicable strictly to free air conditions. To use the 0.45 factor to estimate Buffalo yields, it must be assumed that the partition of energy is unaffected by the ground: this is probably nearly valid for Rounds 1, 3 and 4. For Round 2, however, which was burst actually on the ground, the 0.45 factor might well be in error.

The equivalent TNT charge was calculated separately for each type of gauge and the results were combined, with most weight being given to the FMT results, to give the values for yield quoted below in Table 1.

TABLE 1

Round No.	Equivalent TNT Charge, Thousands of Tons	Total Energy Output, kiloton
1	7.7	17
2	0.46	1
3	1.2	$2\frac{1}{2}$
4	6.75	15

In Table 6 (p. 14), the separate results for each type of gauge are shown with the yield figure again quoted on the basis that 1 kiloton total energy is equivalent in blast effect to 450 tons of TNT.

5.2 Drag Measurements - Commentary on Results

The results indicate that at some points higher stagnation pressures occurred than one would theoretically expect from the local hydrostatic pressure. These results were confirmed by the damage to the girders which supported the gauges, the middle girder on Round 1 being more severely damaged than the one in front of it which was 200 ft nearer Ground Zero. Similarly, the damage to the girder at 1200 ft on Round 3 was more than expected and consistent with the higher pressure recorded. The increase in stagnation pressure may have been caused by a local increase in air density. It was possible that the very fine dust in the area became dispersed in the air in such a finely divided state as to constitute a new fluid with a density approximately twice that of air.

It had been hoped to get more drag gauge data, the intention being to obtain a few results from Round 4 and put the main effort into the air drop weapon, Round 3. The latter, however, was reduced in yield to a point where it was valueless for drag measurements without extensive field engineering to extricate and reposition the girder gauge supports. In an attempt to obtain measurements, three girders were set up on Round 1 at short notice by scientific staff. It is gratifying that the results on Round 1 have proved the most interesting of those obtained.

5.3 Precursor Formation

The quality of the FMT records was such as to give a much clearer picture than before of the pressure/time variations in a precursor region. In particular it can be seen, by comparing the records from Rounds 1 and 4 with those from Round 3, that there are degrees of precursor formation. On Rounds 1 and 4 the multipeaked portion of the record is always preceded by a shock front. This is not so on Round 3. A more detailed examination of wave shape in the precursor region will be reported later when a comparison has been made with the shock front photographs obtained by the Canadian rocket trail team.

TABLE 2

Tower Bursts: Rounds 1 and 4

Table 2a: Round 1

Air temperature 22°C. Barometric pressure 998 mb.
Relative humidity 18%. P = precursor (see Section 4.1, para. 2).

Site	Distance, ft	Pressure, p.s.i.		
		FMT Gauges	Diaphragms	Tubes
AG 101	910			56
AG 103	1030			25
AG 104	1170	36.0 P		20.5
AG 106	1346	27.1 P	28.0 P	7.6
AG 108	1520	22.7 P	14.0 P	3.6
AG 109	1730	20.4 P	15.0 P	6.7
AG 111	1960	15.0 P	15.0 P	10.8
AG 112	2140	13.5	12.5 P	11.0
AG 114	2540	9.76	9.05	7.3
AG 115	2920	7.32	7.20	5.6
AG 117	3330	5.64	5.85	5.1
AG 118	3780	4.65	4.50	4.15
AG 121	4300	3.38	3.85	3.4
AG 123	4860	3.07	3.05	2.5
AG 124	5550	2.61	3.05	2.3

Table 2b: Round 4

Air temperature 13.1°C.
Relative humidity 84%.

Barometric pressure 993.9 mb.
P = precursor (see Section 4.1, Para.2).

Site	Distance, ft	Pressure, p.s.i.		
		FMT Gauges	Diaphragms	Tubes
AG 301	780	-		-
AG 302	880	-		-
AG 303	1000	-		24.7
AG 304	1140	31.9 P		7.1
AG 306	1290	28.1 P		5.5
AG 308	1480	24.4 P	32.7 P	5.5
AG 310	1680	17.8 P	20.2 P	7.9
AG 311	1920	14.2	13.7 P	11.8
AG 312	2180	11.6	11.00	11.1
AG 313	2500	8.88	9.05	8.6
AG 314	2800	7.30	7.50	7.1
AG 315	3230	5.58	5.90	5.7
AG 316	3680	4.47	4.60	4.0
AG 318	4160	4.00	3.85	3.6
AG 319	4740		3.20	3.0

TABLE 3

Ground Burst: Round 2

Air temperature 22.6°C.
Relative humidity, 35%.

Barometric Pressure 992 mb.

Site	Distance, ft	Pressure, p.s.i.		
		FMT Gauges	Diaphragms	Tubes
AG 206	410			45.3
AG 208	470			32.3
AG 209	530	37.0		21.1
AG 211	610	26.0	22.50	27.0
AG 212	690	19.3	18.00	18.00
AG 214	780	15.1	12.70	12.70

TABLE 3 (Contd.)

Site	Distance, ft	Pressure, p.s.i.		
		FMT Gauges	Diaphragms	Tubes
AG 215	870	12.3	10.05	12.1
AG 217	1020	9.30	8.20	9.9
AG 219	1160	7.03	6.80	7.3
AG 220	1330	5.88	5.80	5.6
AG 222	1510	4.80	4.80	4.9
AG 223	1720	3.96	4.05	4.3
AG 225	1960	3.26	3.40	3.4
AG 226		2.67	2.95	2.5
AG 228		2.35	2.45	2.3

TABLE 4

Air Drop: Round 3

Air temperature 24.1 °C.
Relative humidity, 35%.

Barometric pressure 998 mb.
P = precursor (see Section 4.1, para. 2).

Site	Distance, ft	Pressure, p.s.i.		
		FMT Gauges	Diaphragms	Tubes
AG 401	-			
AG 402	-			63*
AG 403	-			
AG 403/1	300			43.8
AG 403/2	420			35.8
AG 405	580	15.9 P		43.6
AG 405/1	740	24.7 P		3.7
AG 407	990	16.4 P		2.8
AG 408	1320	9.87 P		0
AG 411	1750	8.90	9.05	7.6
AG 414	2290	5.84	6.00	5.6
AG 416	2850	4.23	4.45	3.8
AG 419	3440	3.08	3.05	3.0
AG 422	3990	2.44	2.60	2.3

* Over 85 on remote site of Ground Zero.

TABLE 5

Drag Gauge Results

Round	Distance from Ground Zero, ft	Height of Gauge above Ground, ft	Peak Stagnation Pressure Recorded, p.s.i.	Theoretical Stagnation Pressure Based on FMT, p.s.i.
1	1358	$8\frac{1}{2}$	38.6	46.5
		3	46.2	
	1545	$8\frac{1}{2}$	52.0	34.0
		3	80.0	
	2171	$8\frac{1}{2}$	16.8	17.0
		3	15.0	
4	1200	10	No result	70.0
		3	83.0	
	1400	10	48.5	40.0
		3	64.0	
	1600	10	8.5†	28.0
		3	35	
3	1200*	10	68	29
		3	No result	
	1800*	10	12.0	12

* Distance from Kite.
† Records went off paper.

TABLE 6

Buffalo Yield Results

Round	Gauge	Scale Factor to 1 kiloton Total Energy	Yield kiloton Total Energy
1	FMT	2,59	17.4
	Tubes	2.22	10.9
	Diaphragms	2.55	16.6
2	FMT	1.01	1.03
	Tubes	1.05	1.16
	Diaphragms	0.98	0.94
3	FMT	1.37	2.6
	Tubes	1.30	2.20
	Diaphragms	1.40	2.7
4	FMT	2.45	14.7
	Tubes	2.40	13.8
	Diaphragms	2.50	15.6

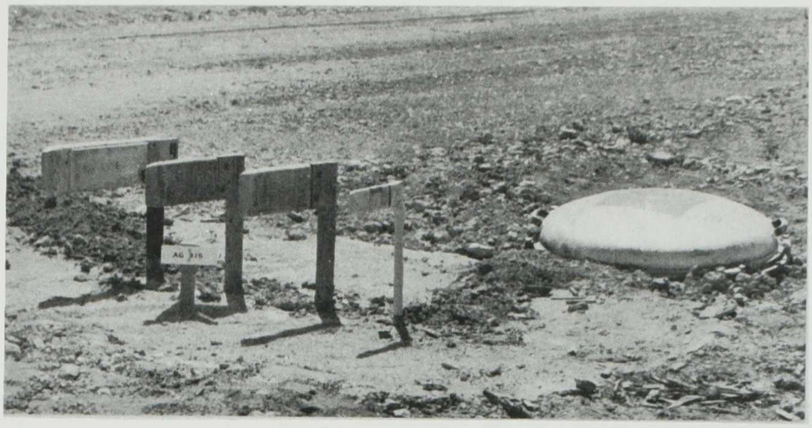

FIG. 1. BLAST GAUGE SITE, SHOWING (RIGHT TO LEFT) F.M.T. CONTAINER, F.M.T. GAUGE, TWO BAFFLES, & DIAPHRAGM GAUGE.

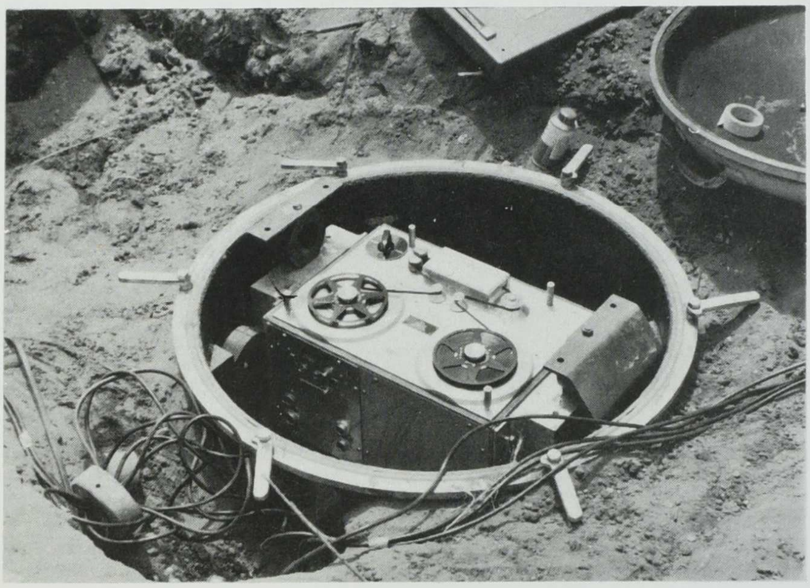

FIG. 2. F.M.T CONTAINER WITH LID REMOVED SHOWING TAPE DECK.

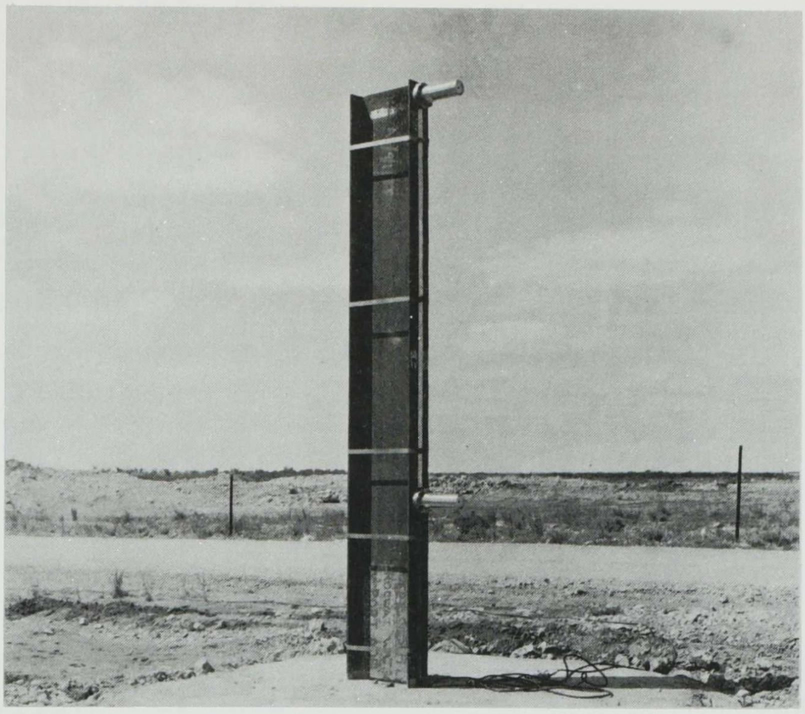

FIG. 3. DRAG GAUGES AT TWO HEIGHTS ON MAST.

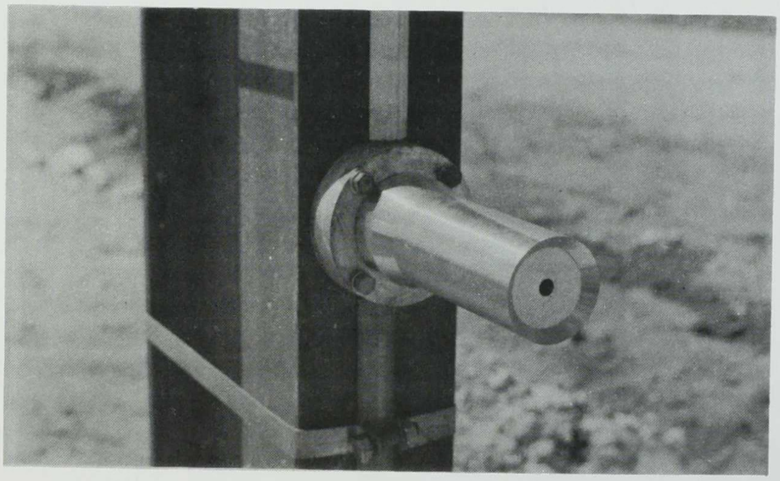

FIG. 4. DRAG GAUGE CLOSE-UP.

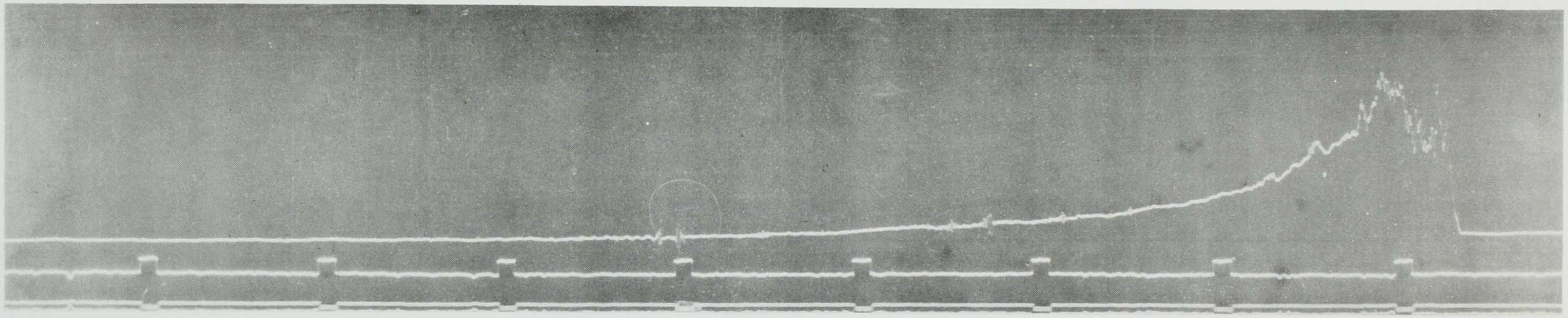

FIG. 5. AG 104 1170 FT. 36 P.S.I.

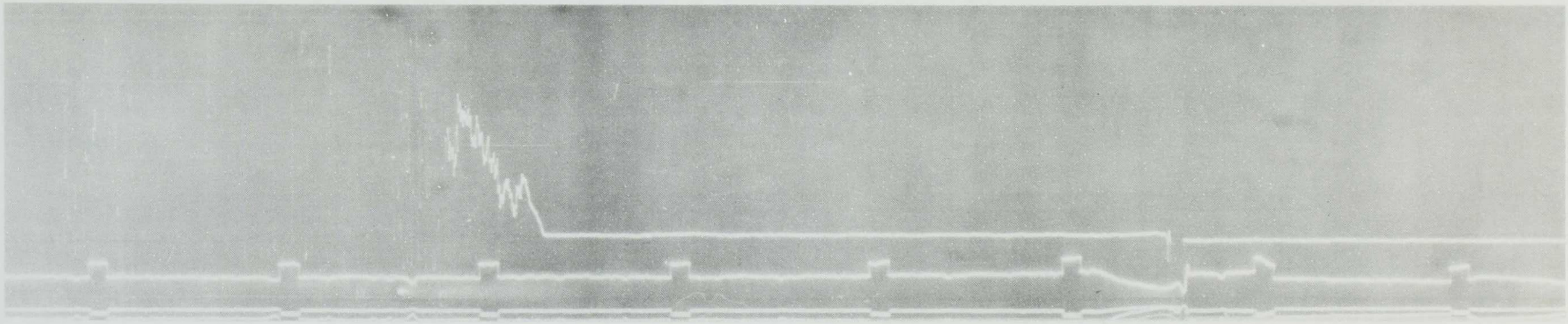

FIG. 6. AG 106 1350 FT. 27 P.S.I.

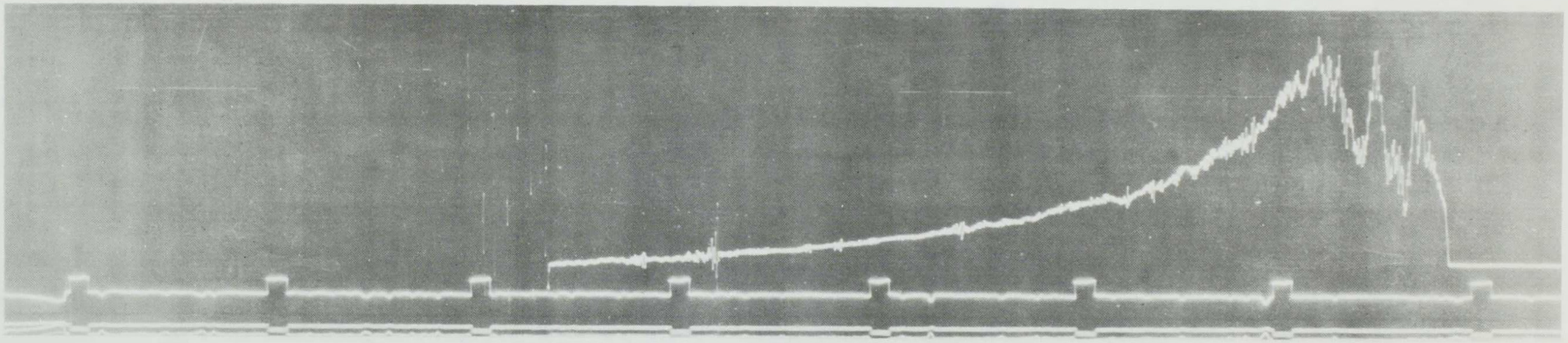

FIG.7. AG 108 1520 FT. 22·7 P.S.I.

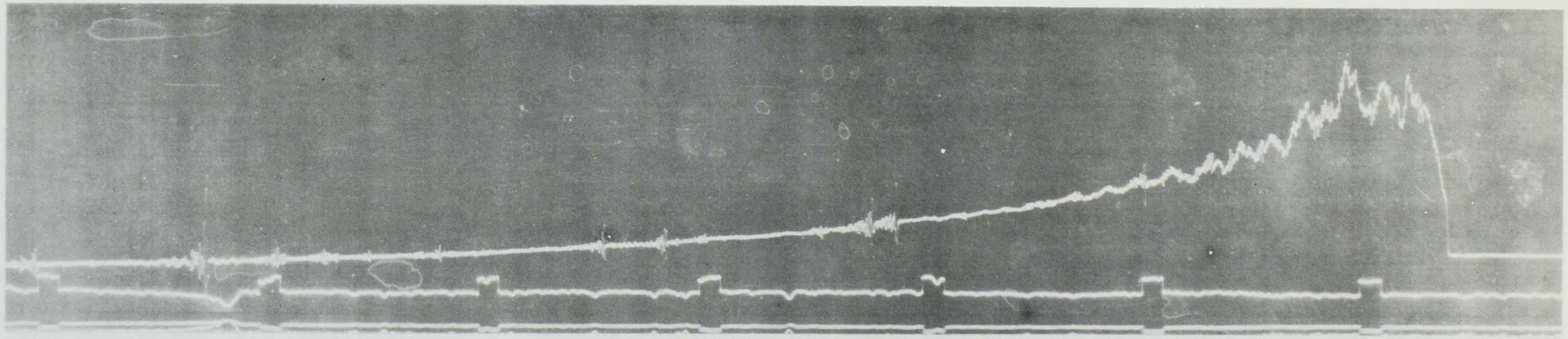

FIG.8. AG 109 1730 FT. 20·4 P.S.I.

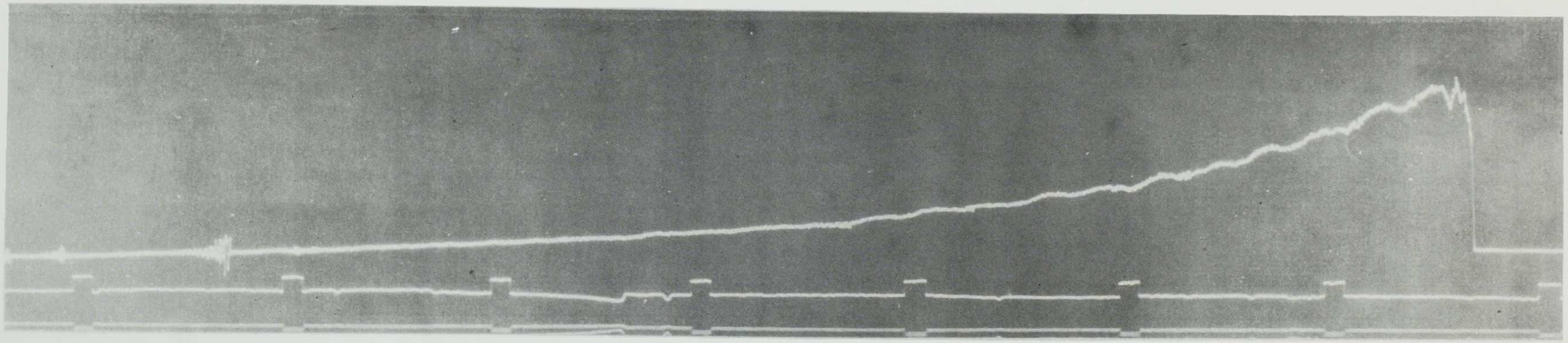

FIG. 9. AG 111 1960 FT. 15 P.S.I.

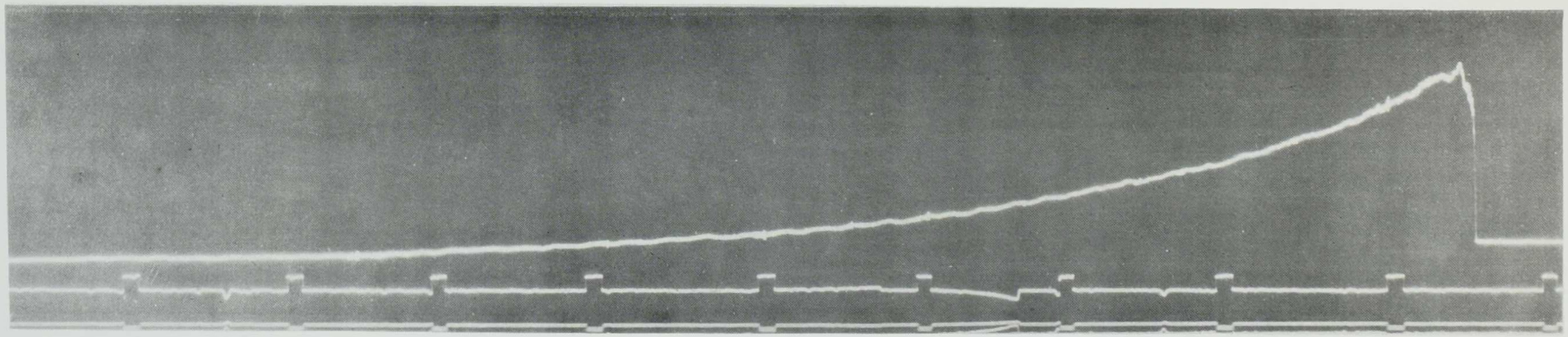

FIG. 10. AG 112 2140 FT. 13·5 P.S.I.

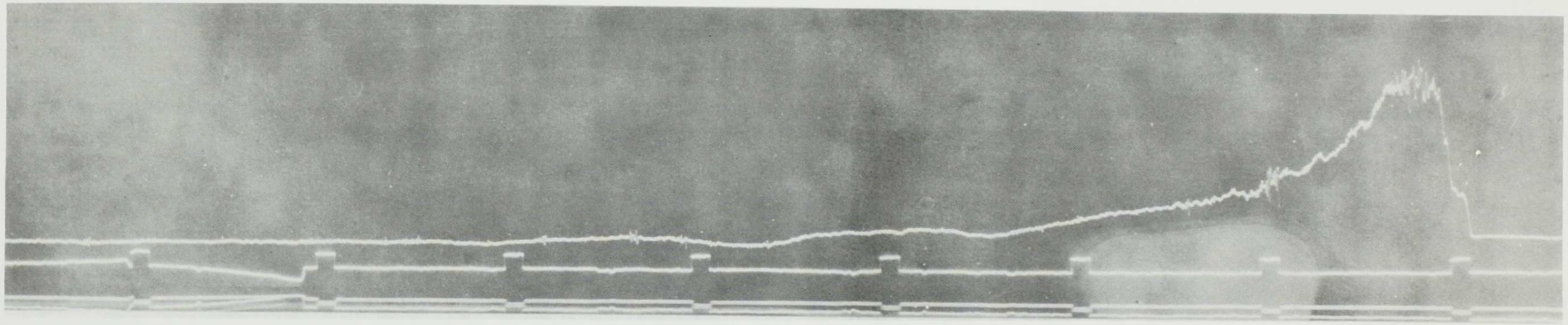

FIG. 11. AG 304 1140 FT. 32 P.S.I.

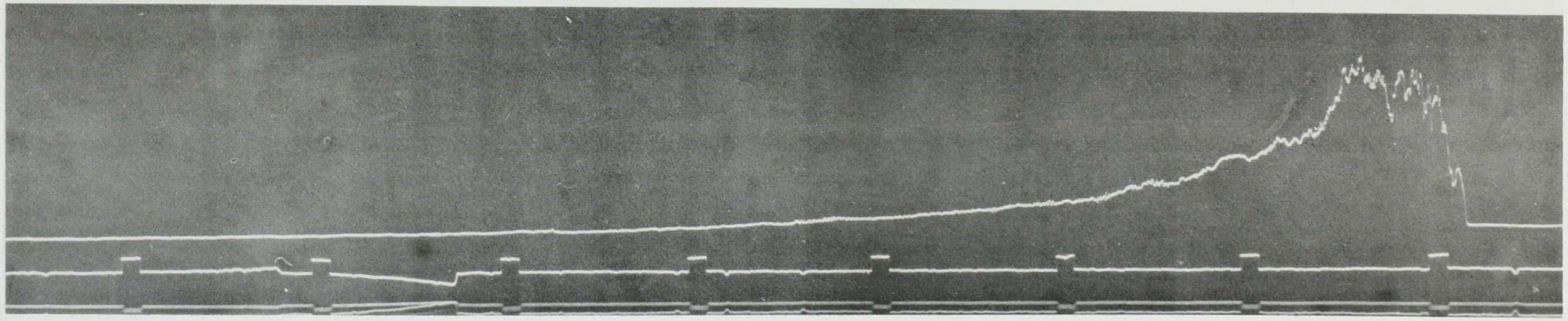

FIG. 12. AG 306 1290 FT. 28 P.S.I.

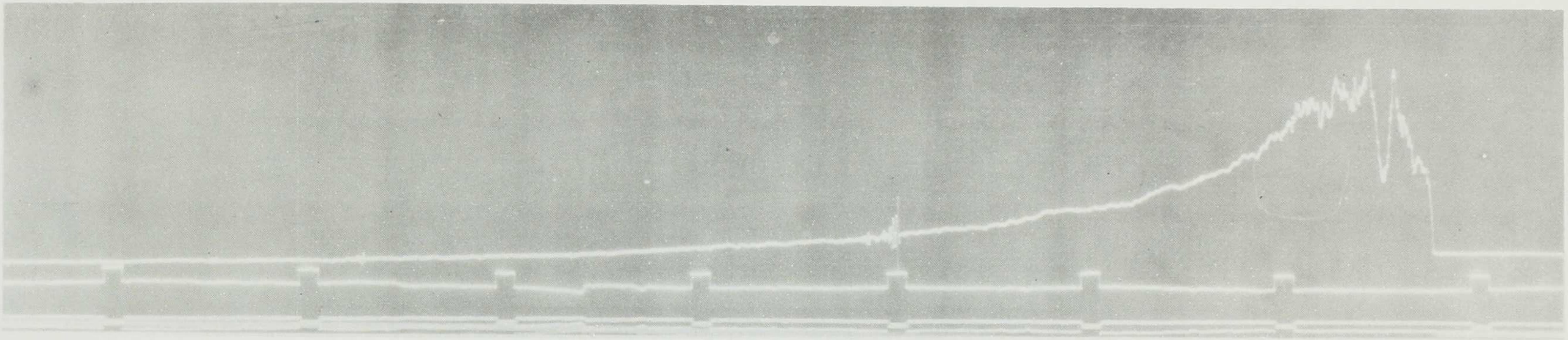

FIG. 13. AG 308 1480 FT. 24·4 P.S.I.

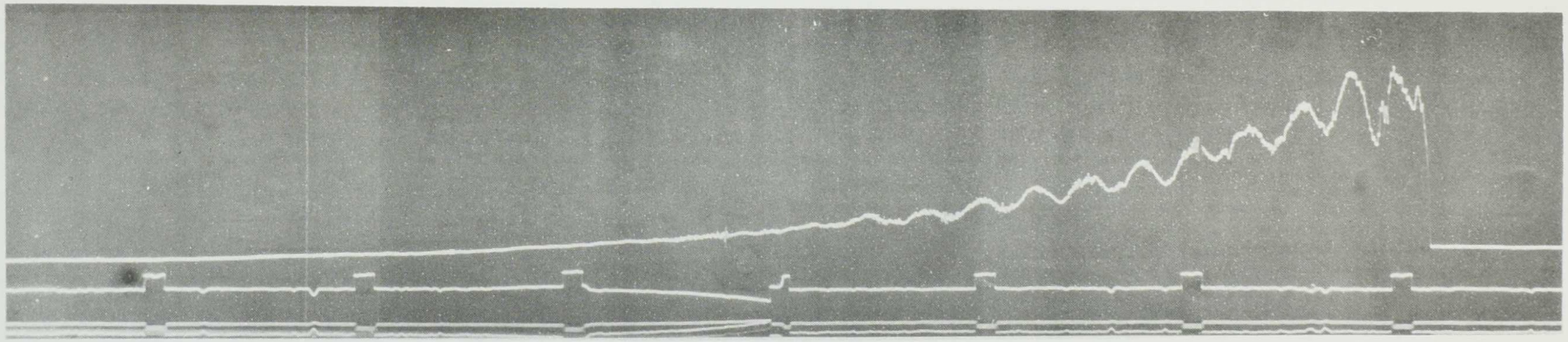

FIG. 14. AG 310 1680 FT. 17·8 P.S.I.

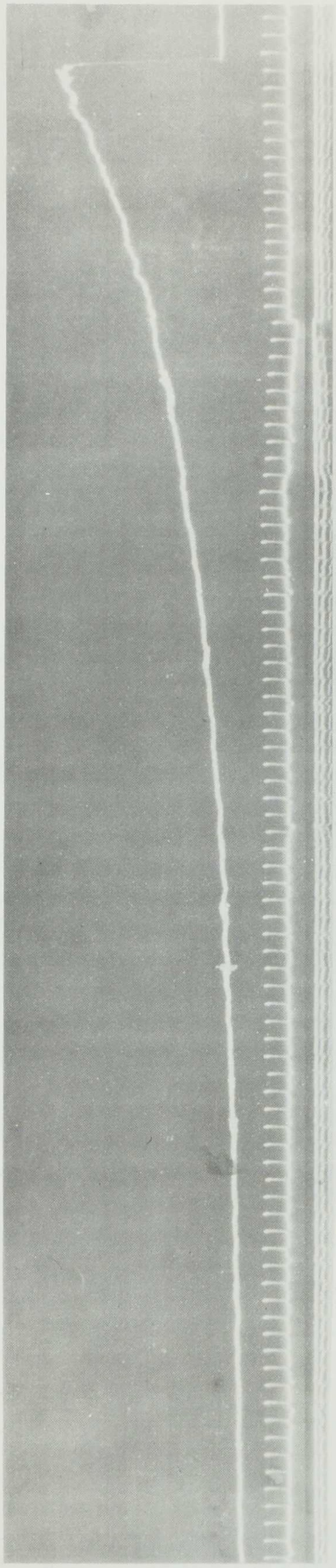

FIG. 15. AG 311 1920 FT. 14·2 P.S.I.

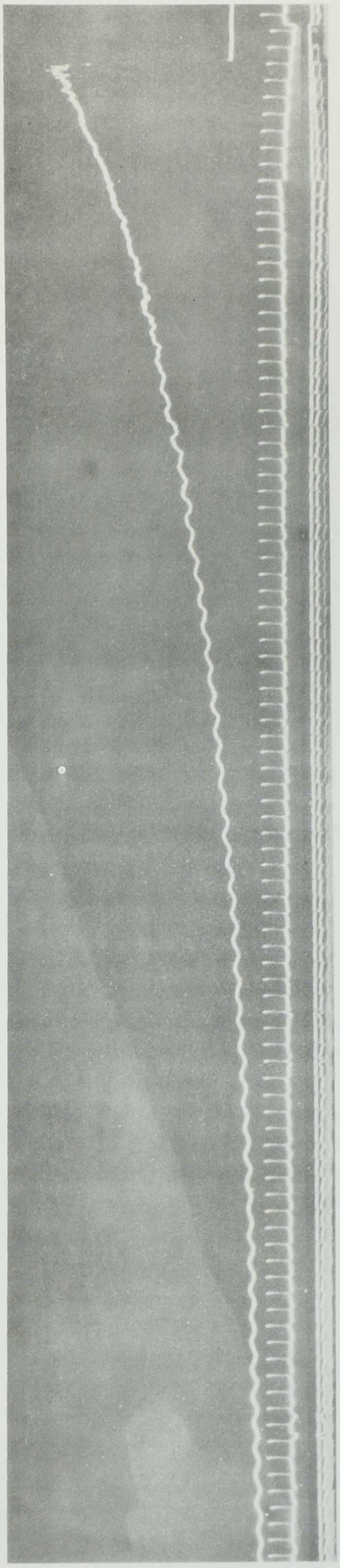

FIG. 16. AG 312 2180 FT. 11·6 P.S.I.

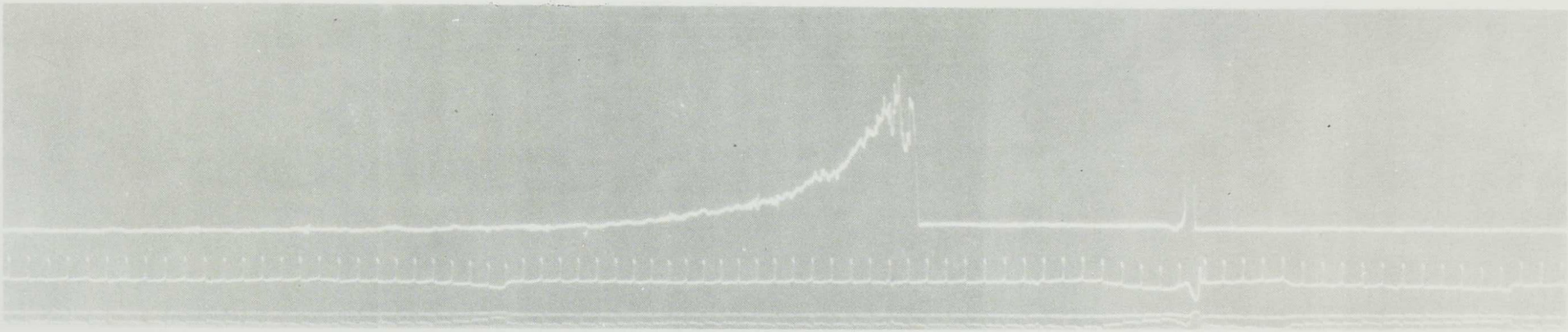

FIG. 17. AG 209 530 FT. 37 P.S.I.

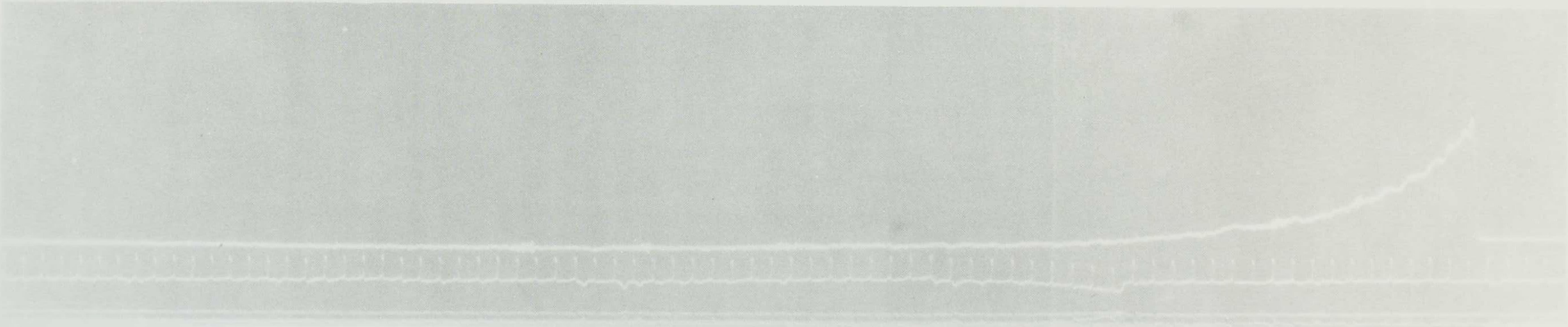

FIG. 18. AG 211 610 FT. 26 P.S.I.

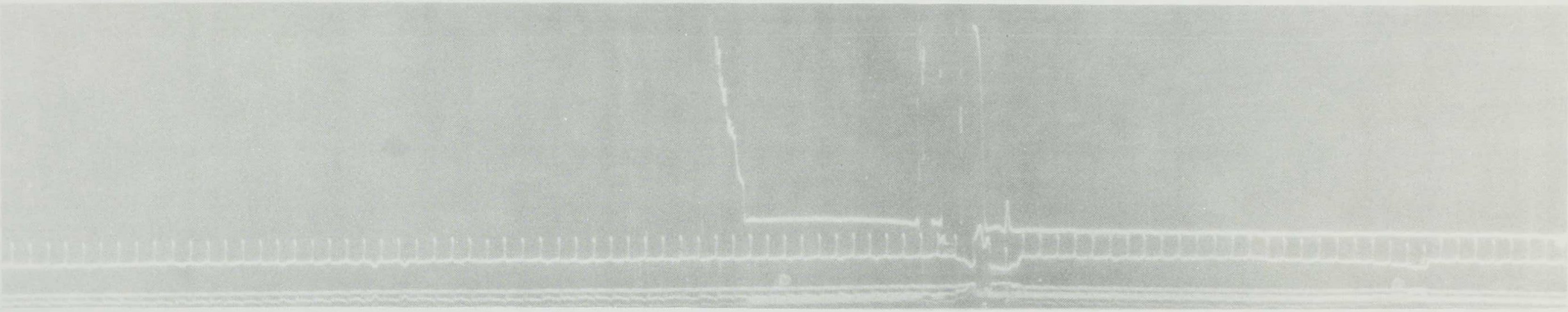

FIG. 19. AG 403/2 420 FT.

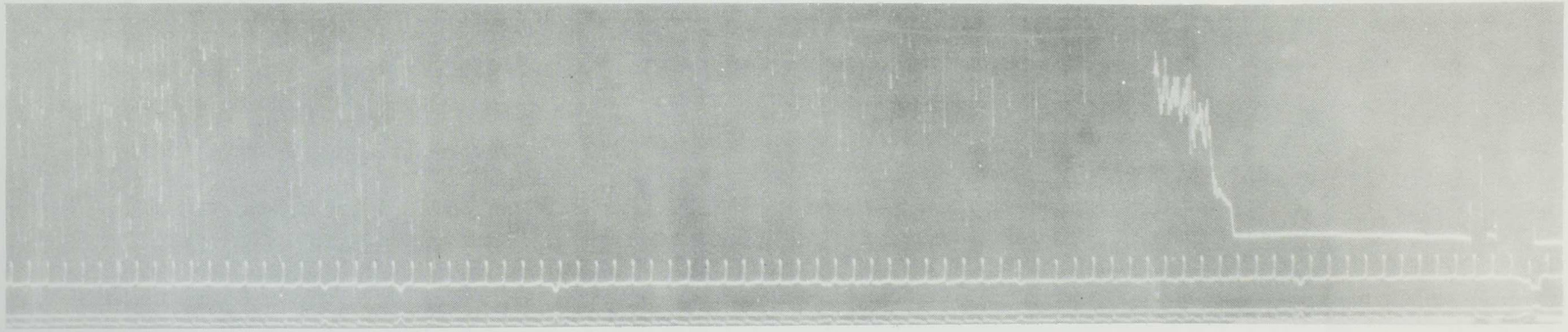

FIG. 20. AG 405 580 FT. 15·9 P.S.I.

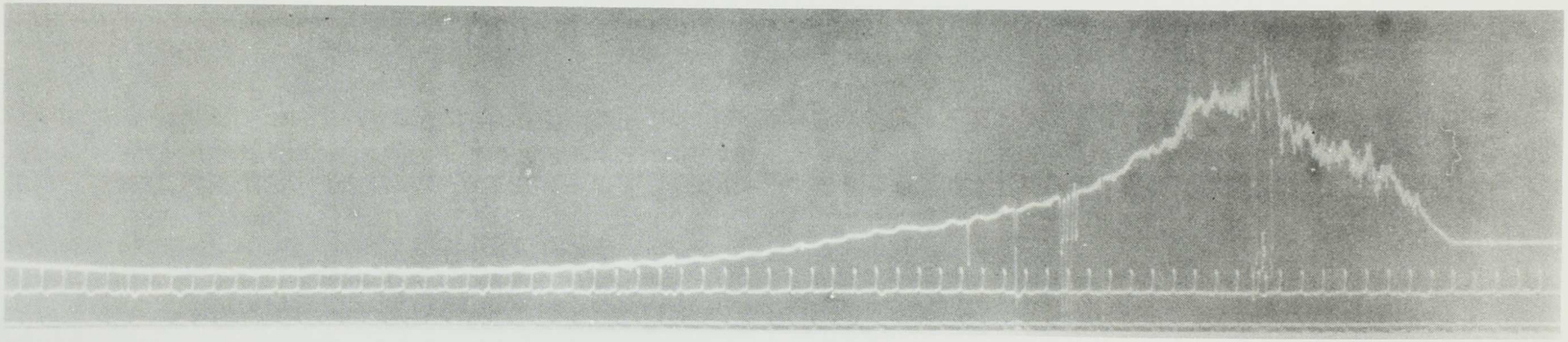

FIG. 21. AG 405/1 740 FT. 24·7 P.S.I.

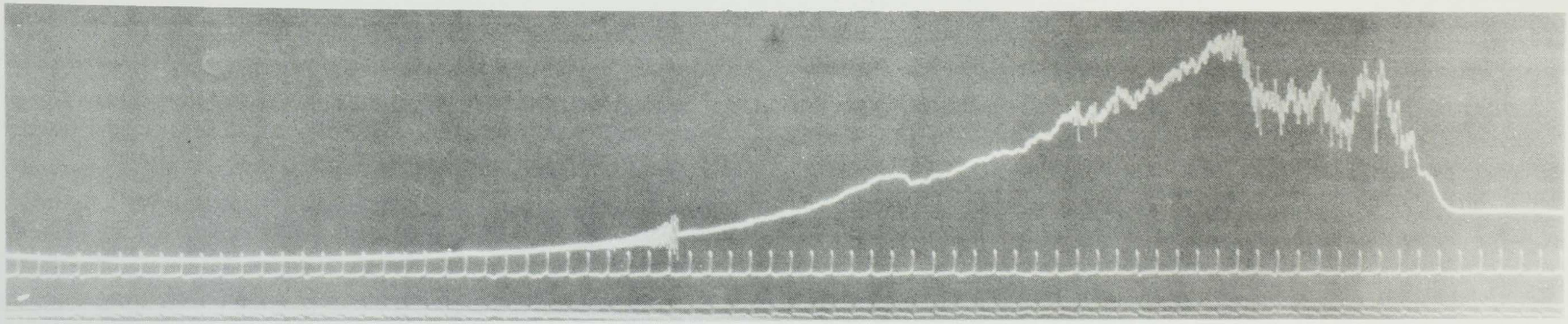

FIG. 22. AG 407 990 FT. 16·4 P.S.I.

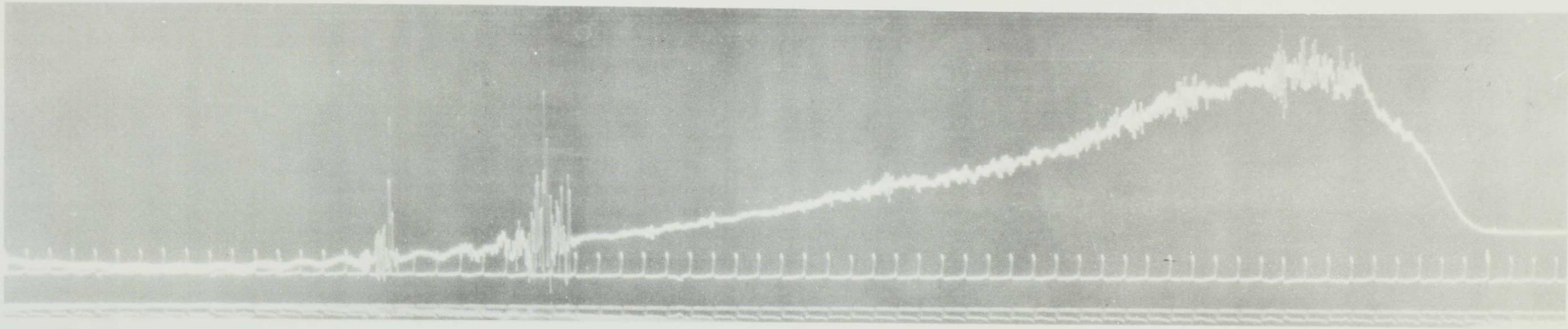

FIG. 23. AG 408 1320 FT. 9·9 P.S.I.

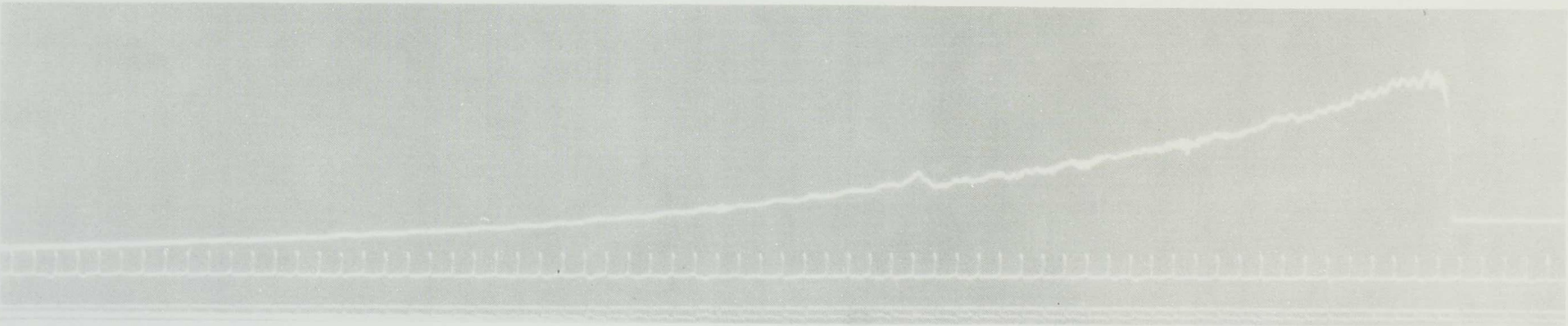

FIG. 24. AG 411 1750 FT. 8·9 P.S.I.

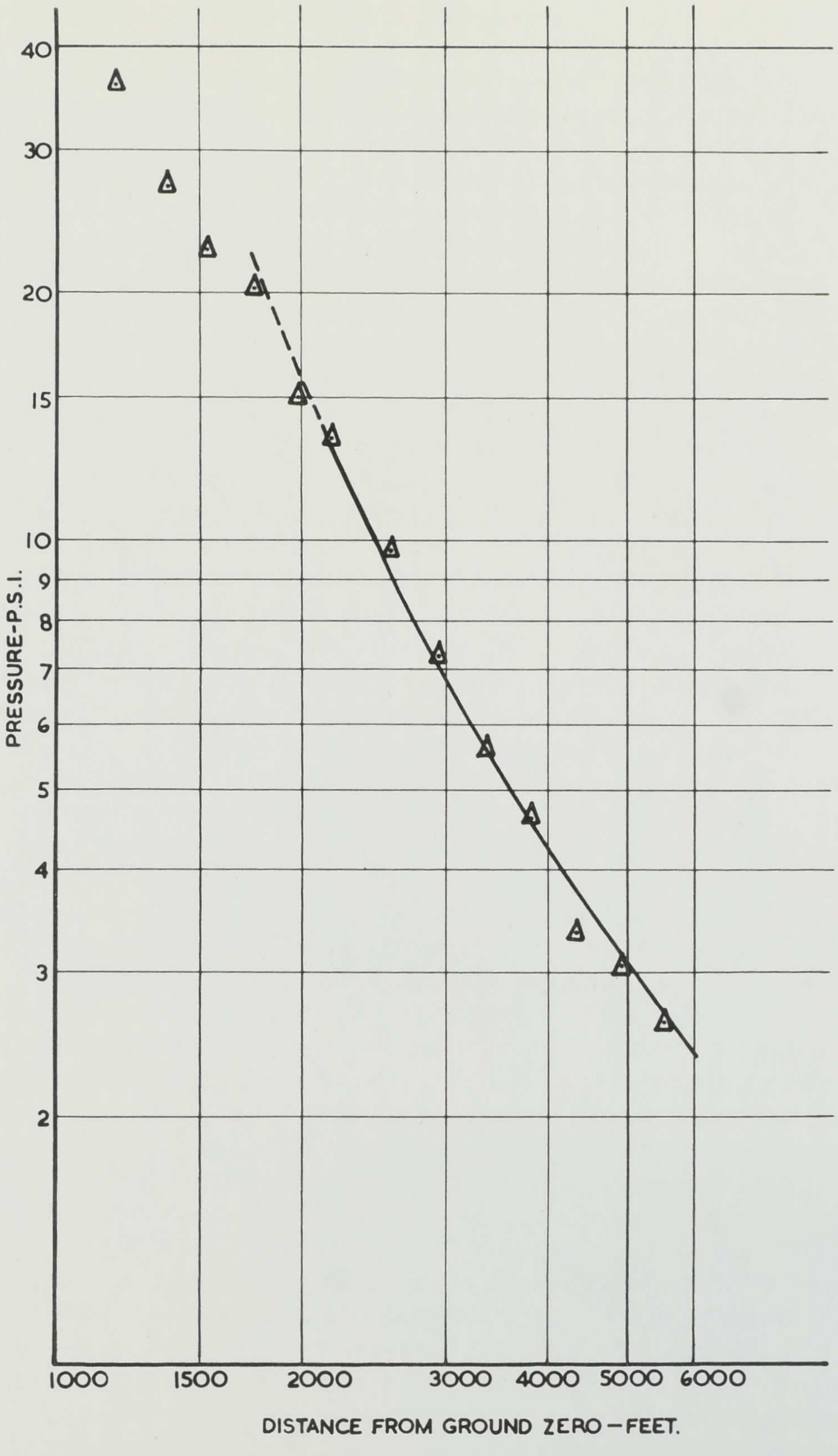

FIG.25. ROUND.1. — PRESSURE/DISTANCE CURVE. FMT. RESULTS.

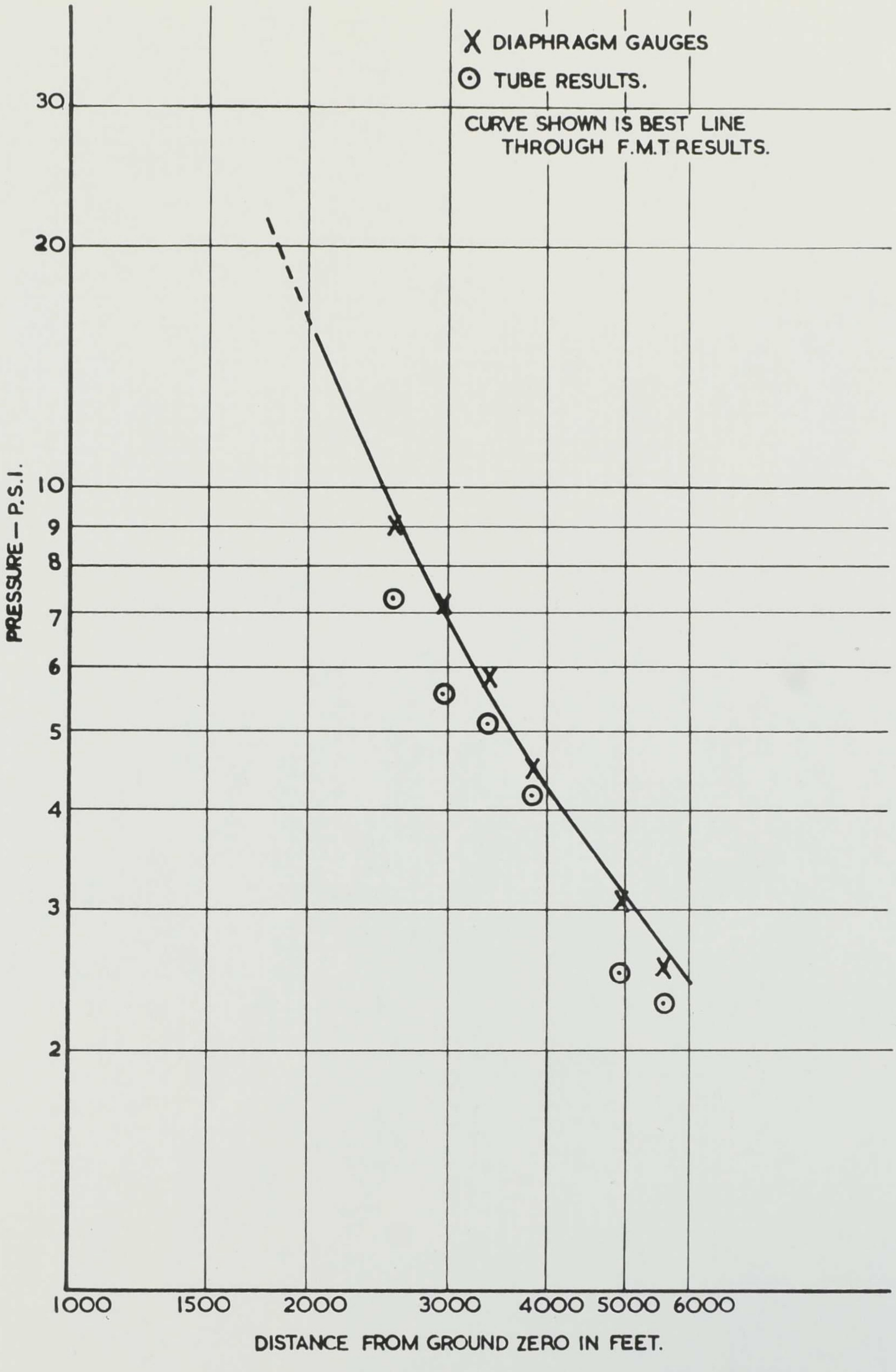

FIG. 26. ROUND. I.—PRESSURE/DISTANCE CURVE. DIAPHRAGM & TUBE RESULTS.

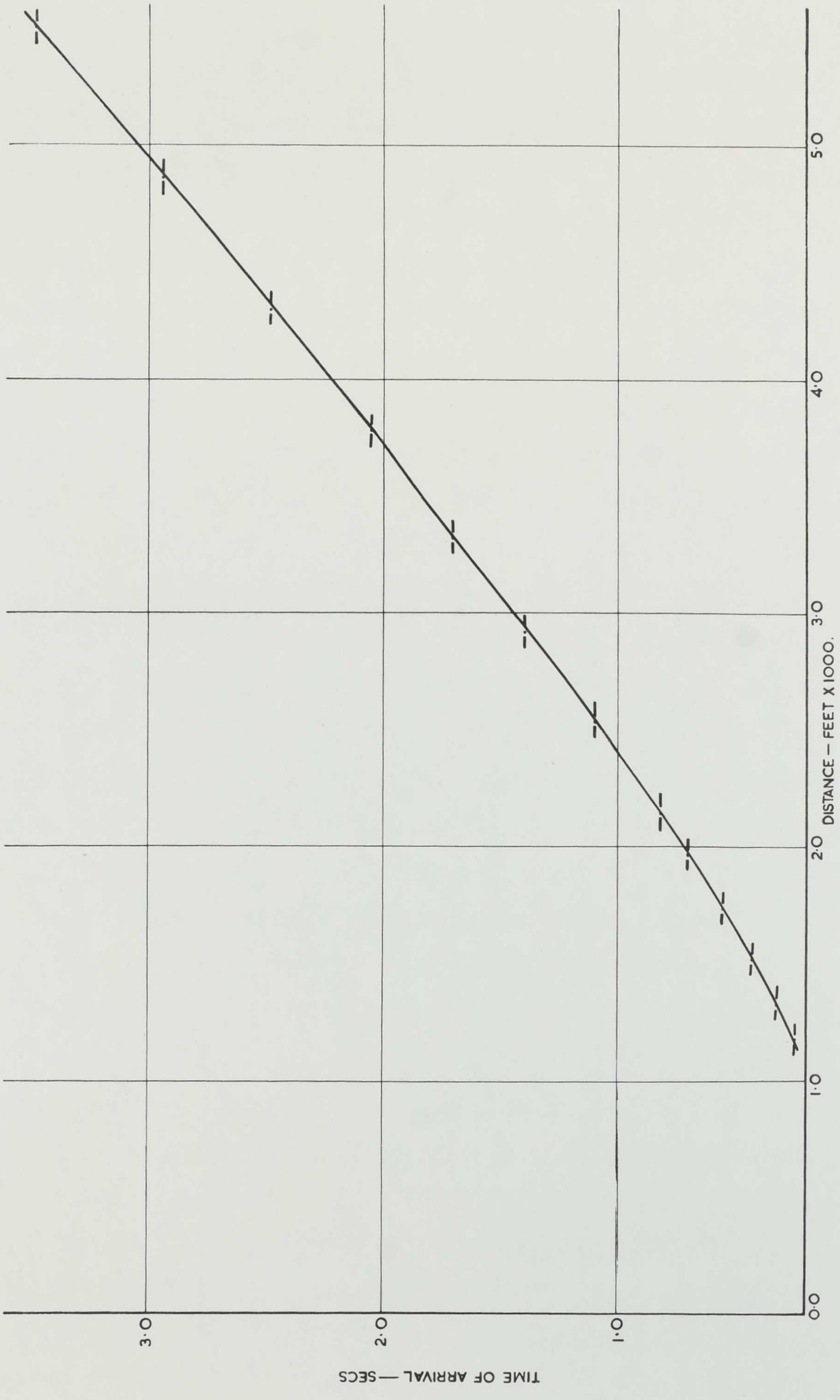

FIG. 27. ROUND. 1. – DISTANCE/TIME CURVE.

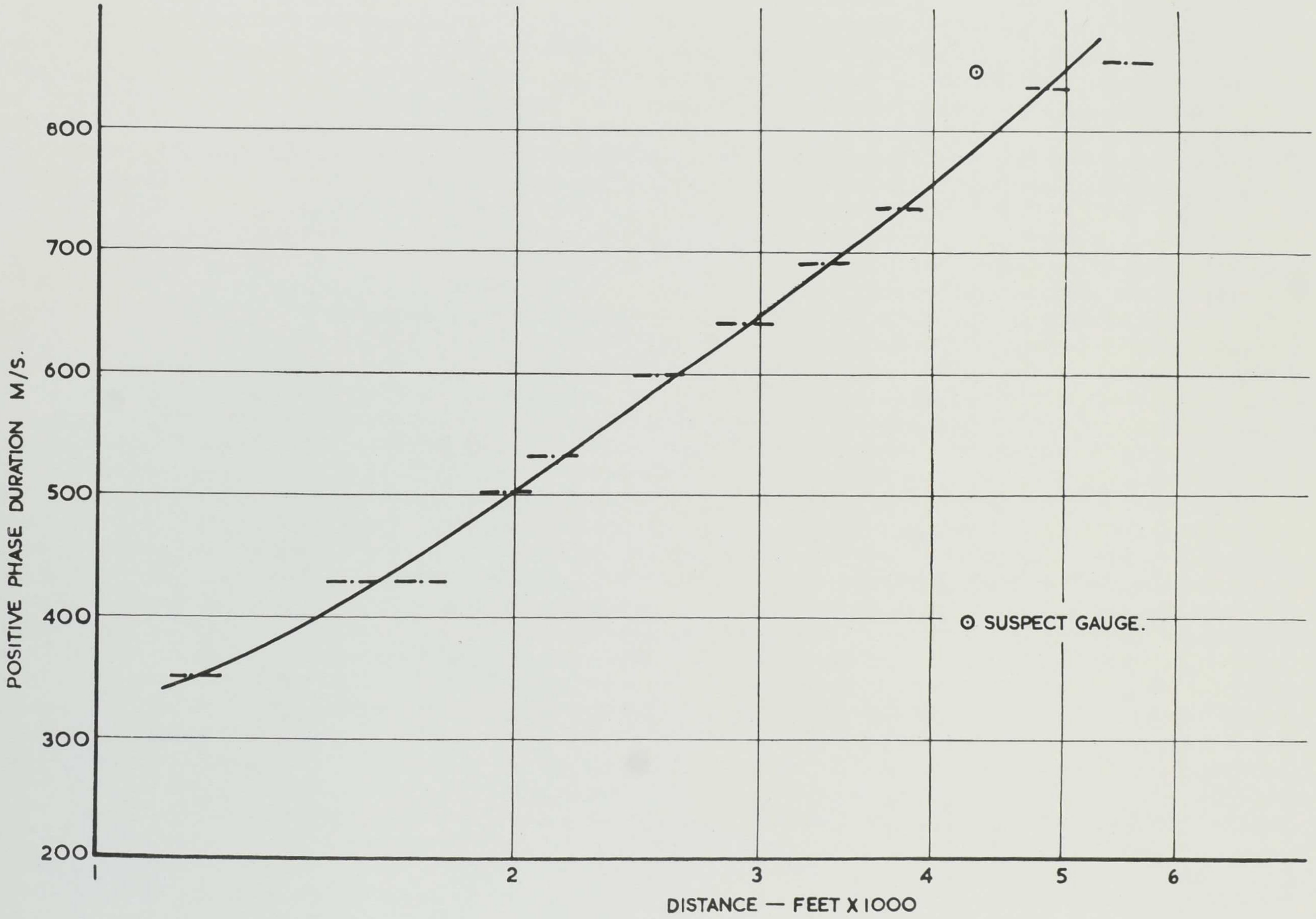

FIG. 28. ROUND.I. — DISTANCE/PHASE DURATION CURVE.

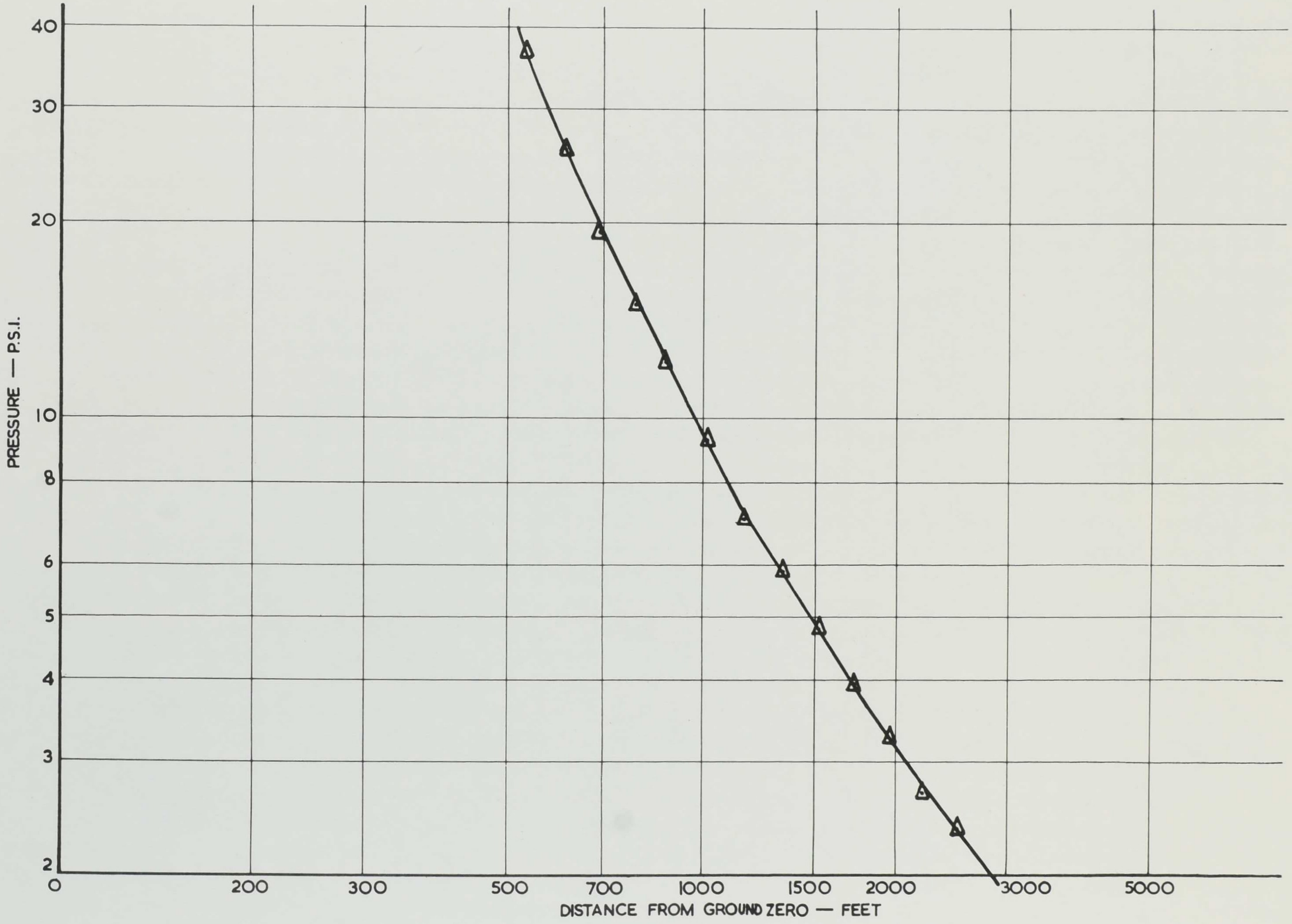

FIG. 29. ROUND 2. – PRESSURE/DISTANCE CURVE FMT RESULTS.

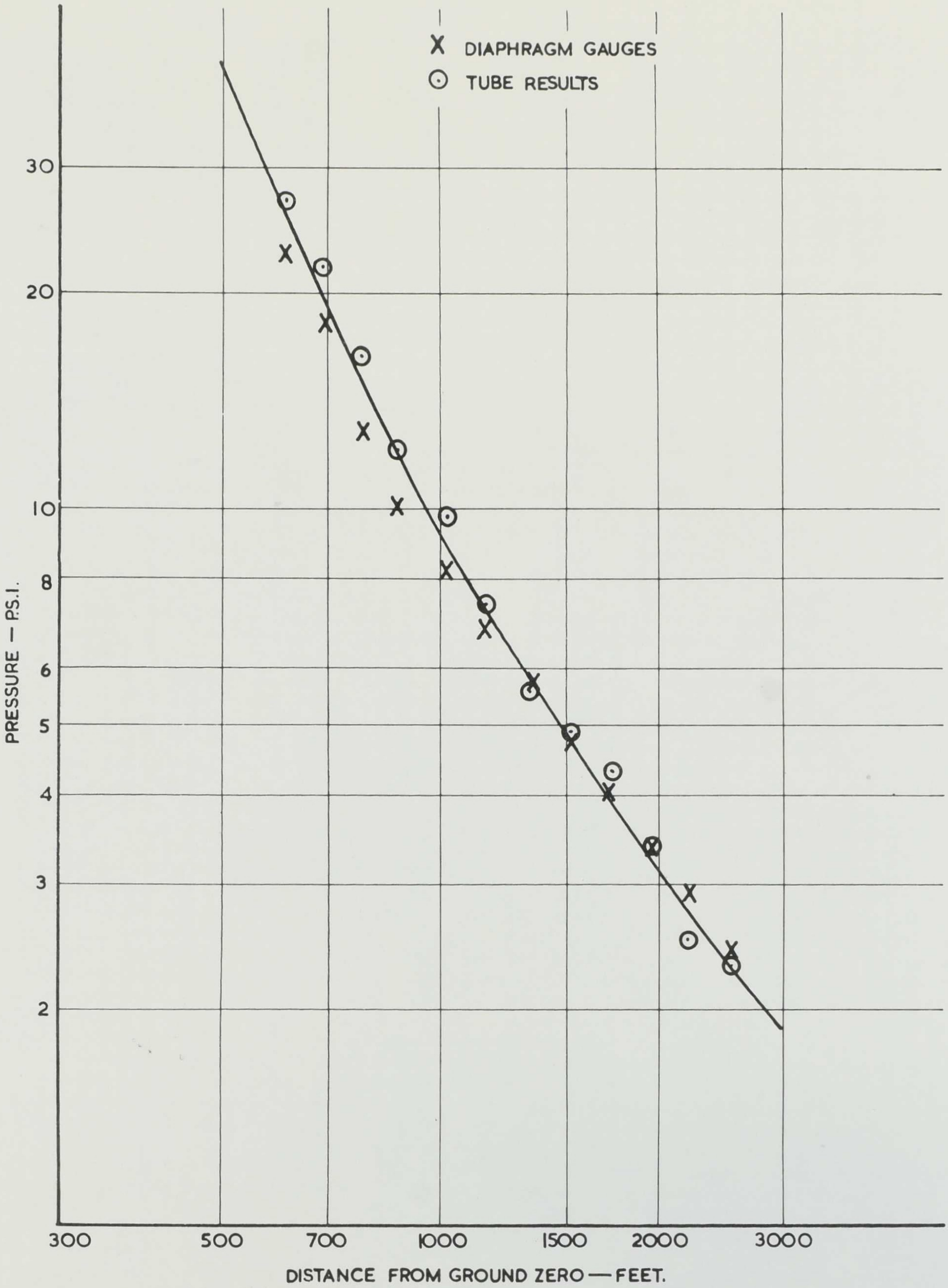

FIG. 30. ROUND 2. — PRESSURE / DISTANCE CURVE. DIAPHRAGM & TUBE RESULTS

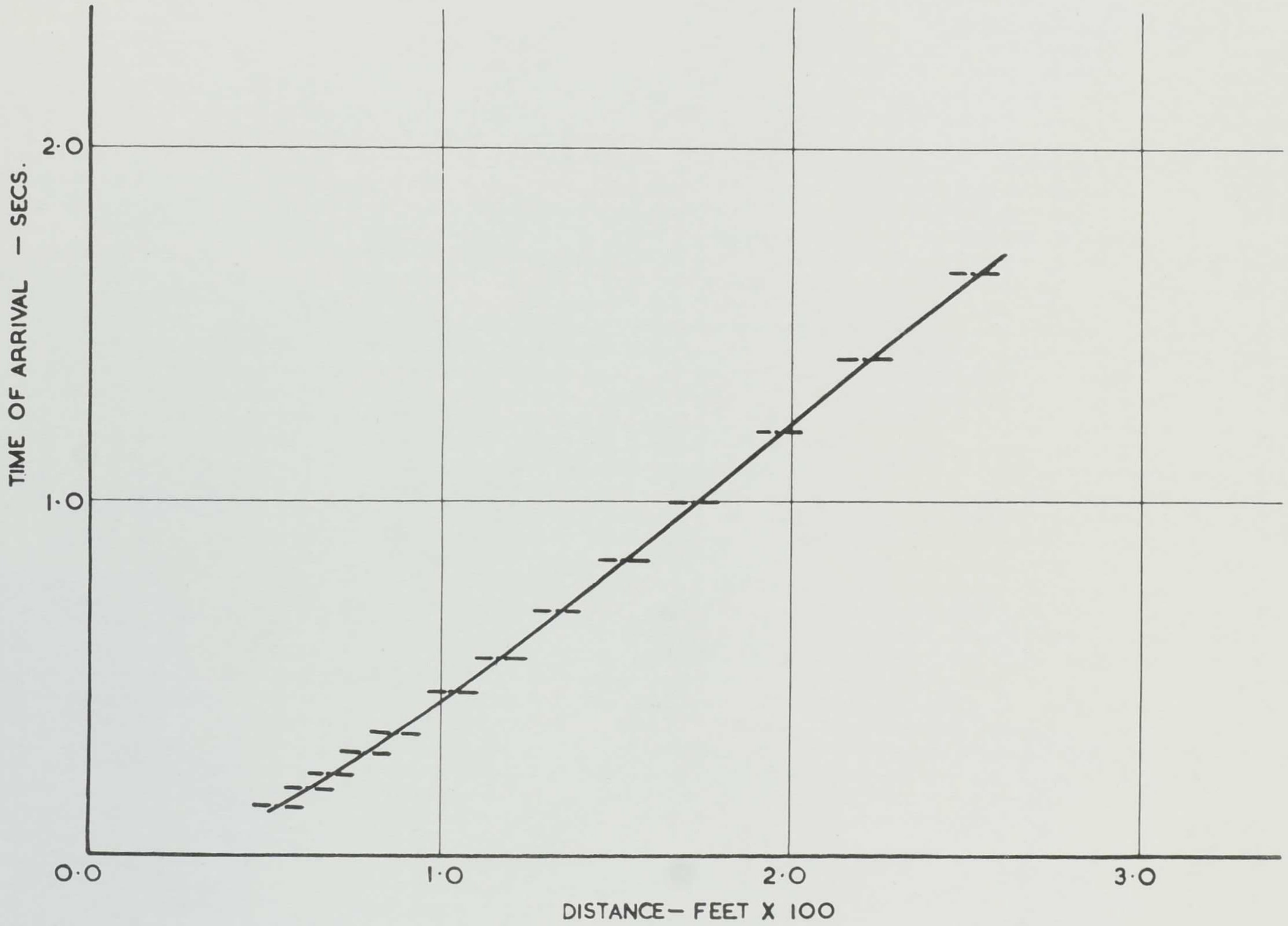

FIG. 31. ROUND 2. — DISTANCE / TIME CURVE.

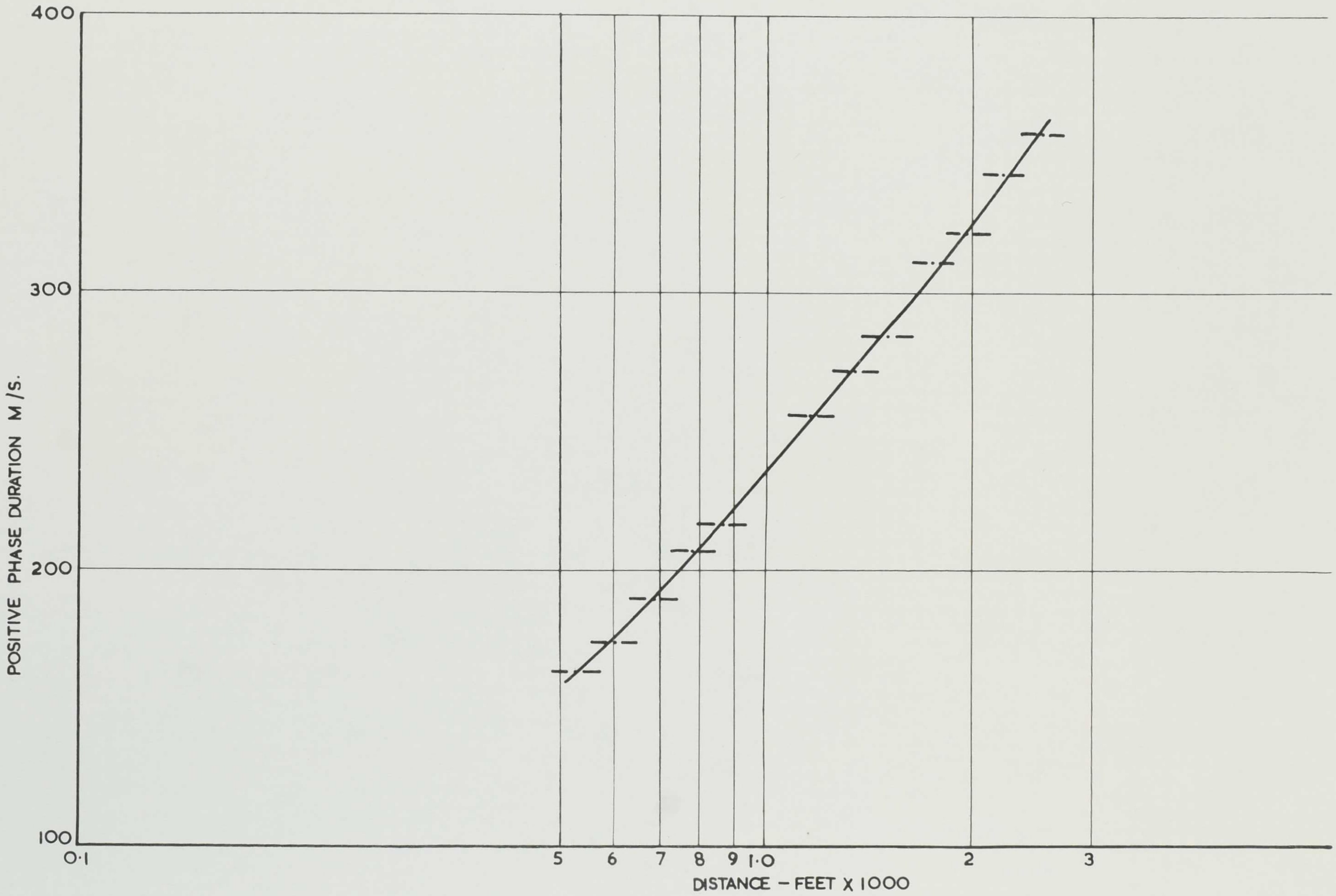

FIG. 32. ROUND 2. – DISTANCE / PHASE DURATION CURVE.

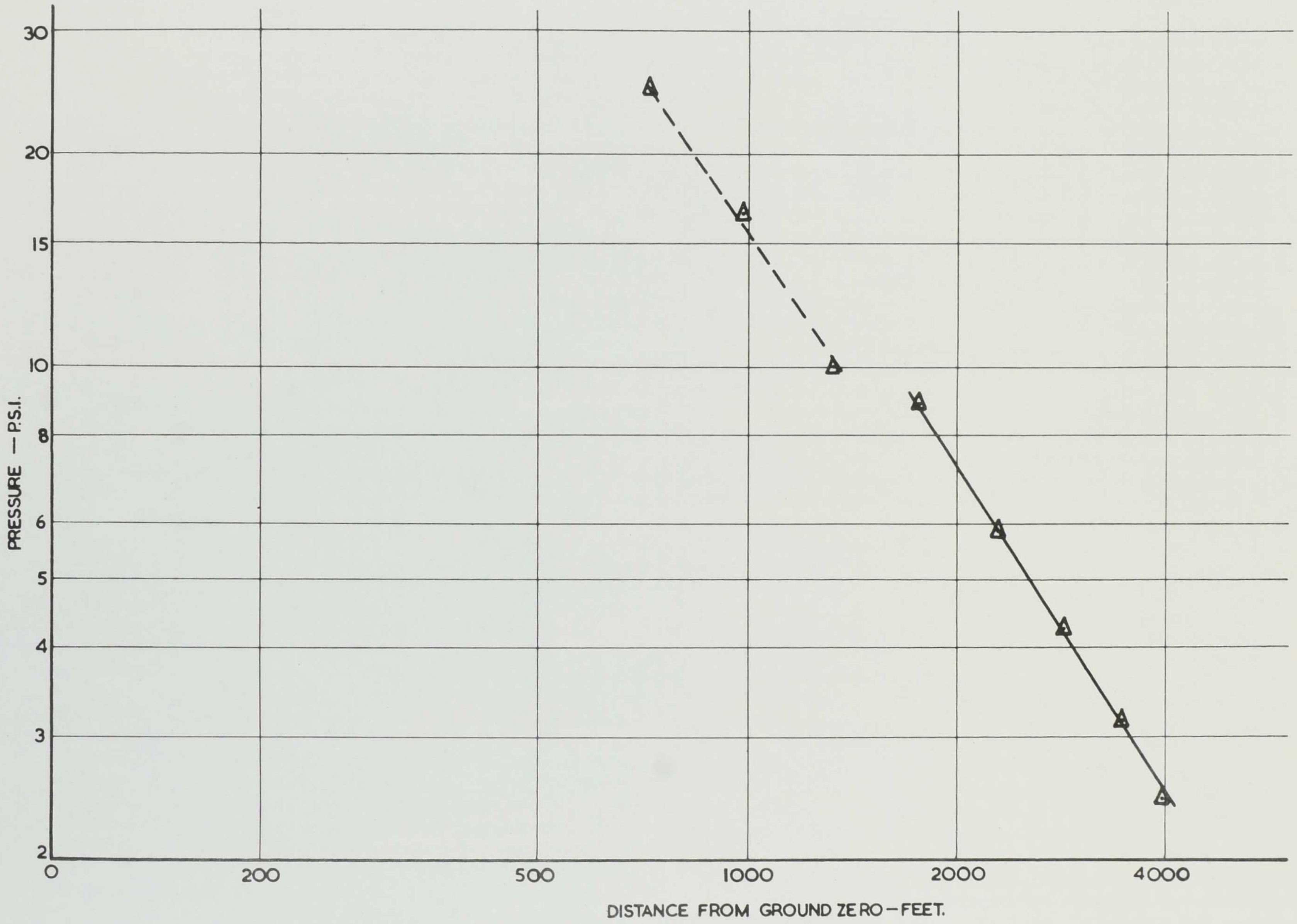

FIG. 33. ROUND 3.-PRESSURE/DISTANCE CURVES FMT RESULTS.

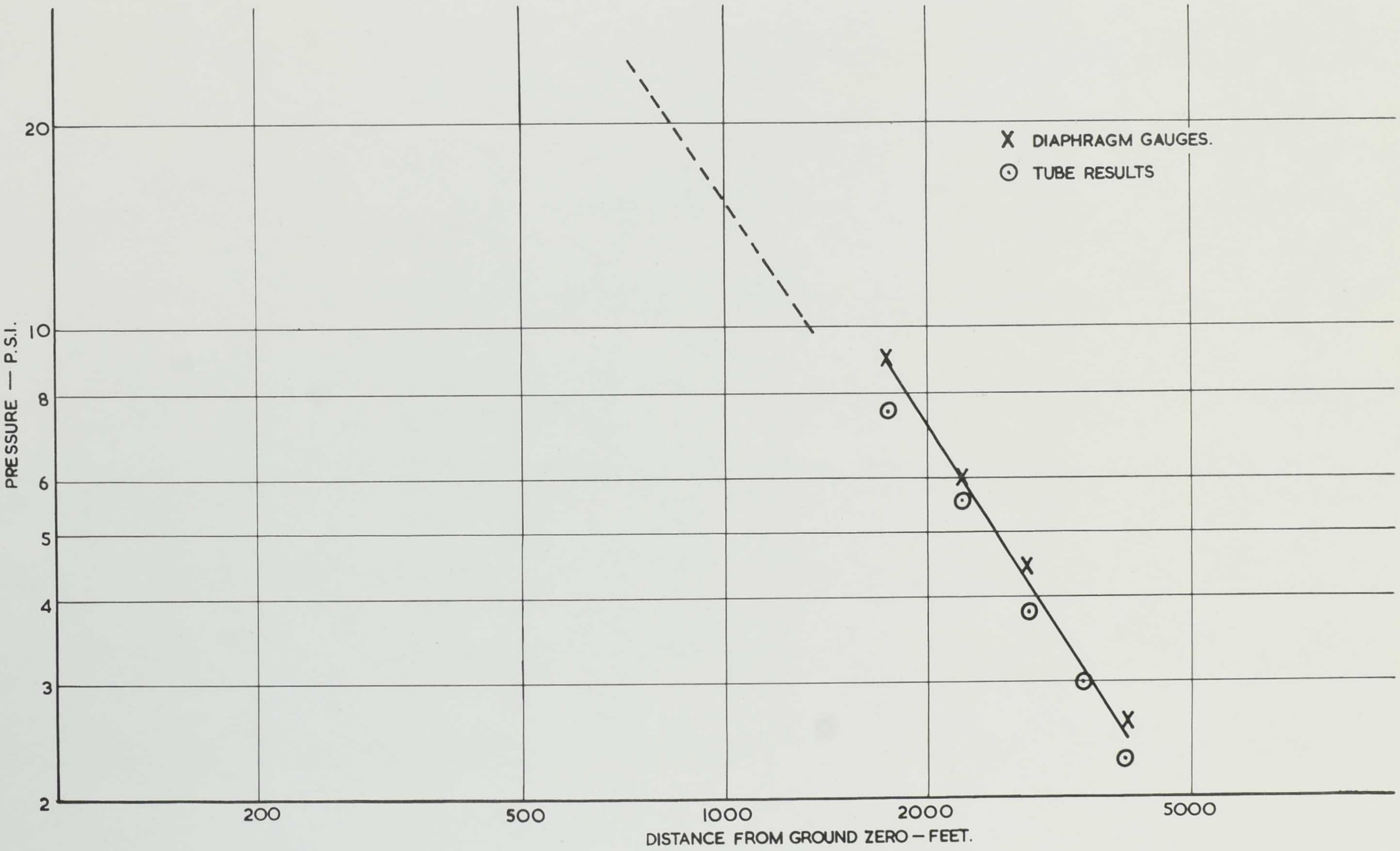

FIG. 34. ROUND 3. – PRESSURE / DISTANCE CURVES DIAPHRAGM & TUBE RESULTS.

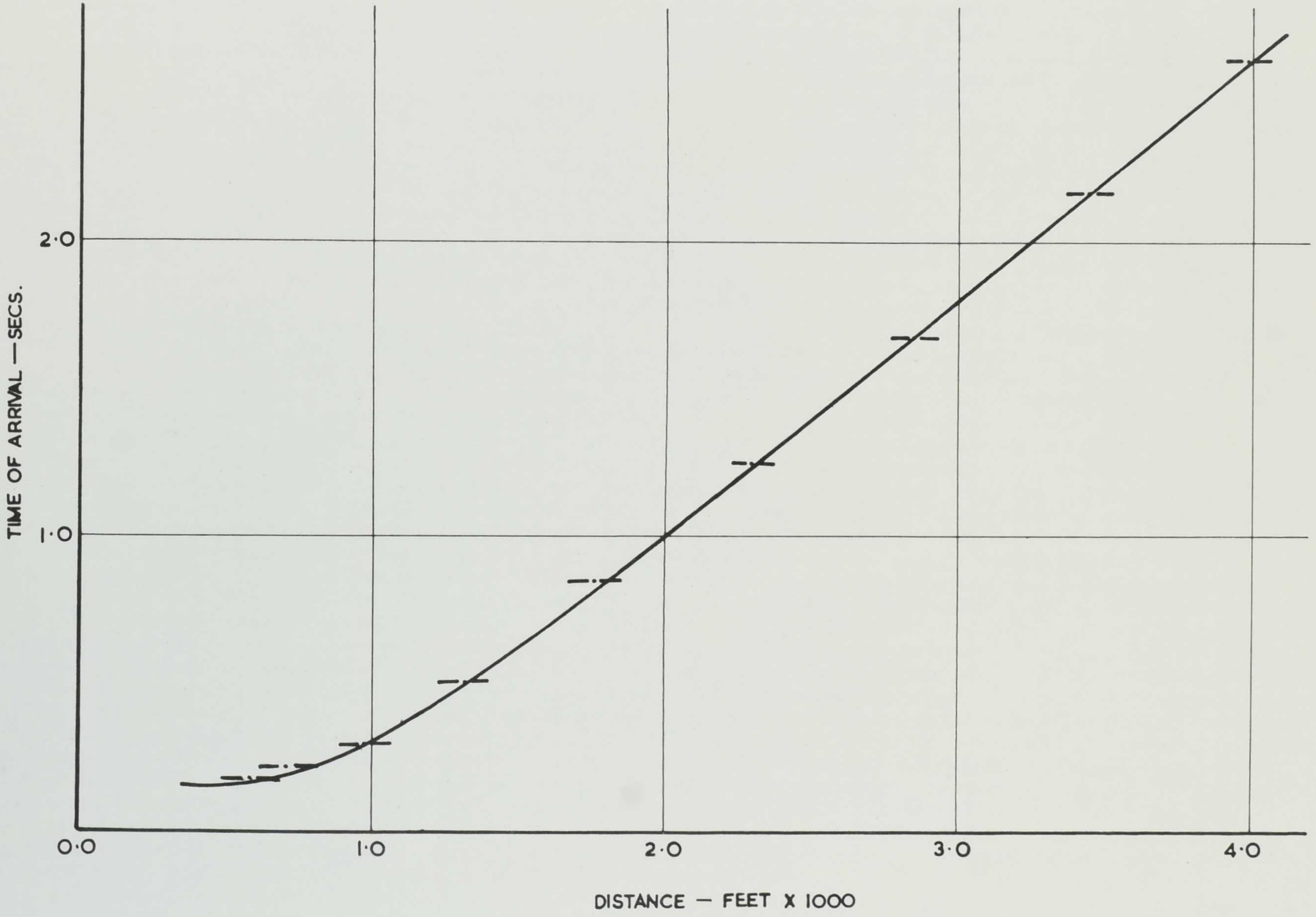

FIG.35. ROUND 3.—DISTANCE/TIME CURVE.

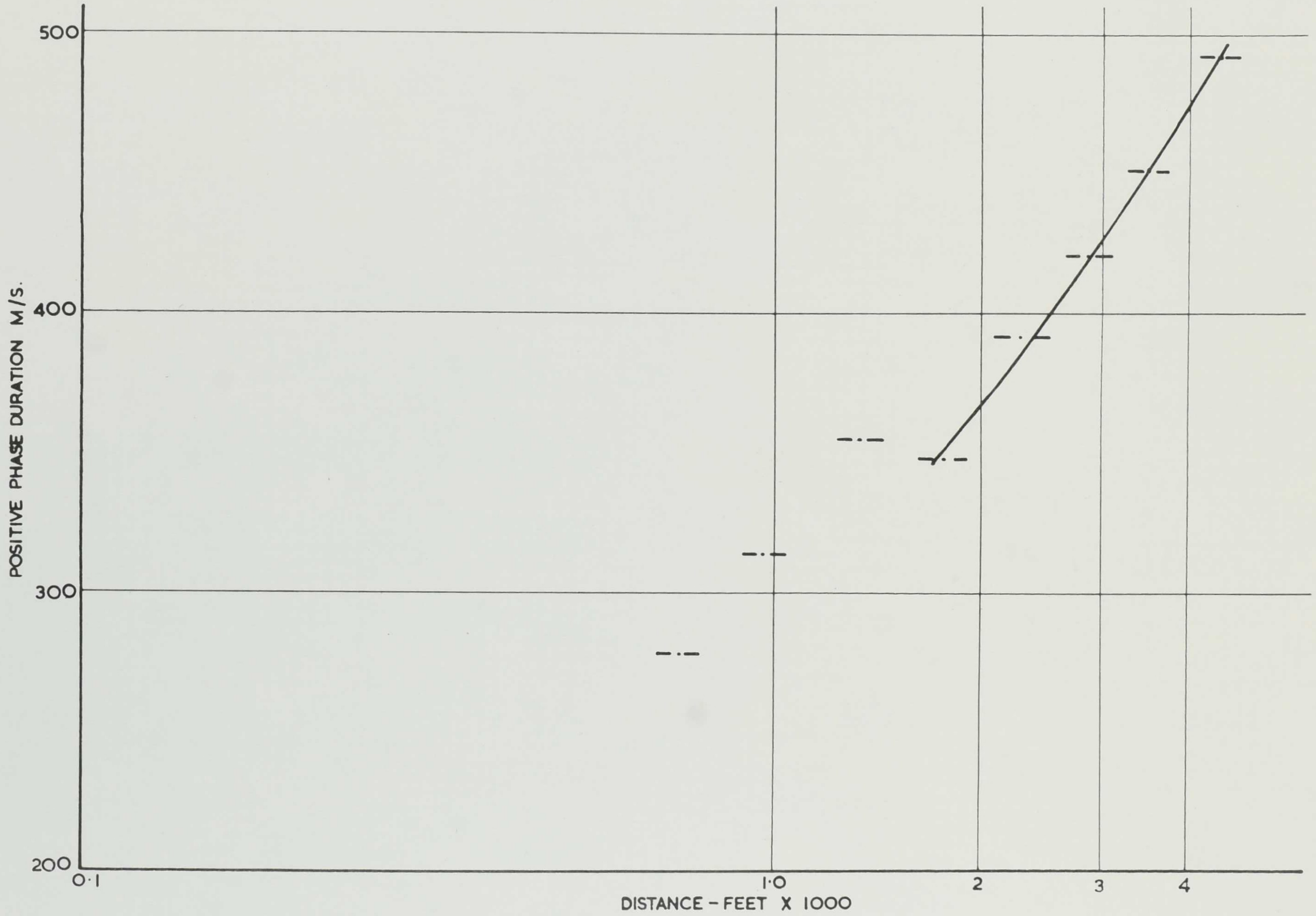

FIG. 36. ROUND 3. — DISTANCE / PHASE DURATION CURVE.

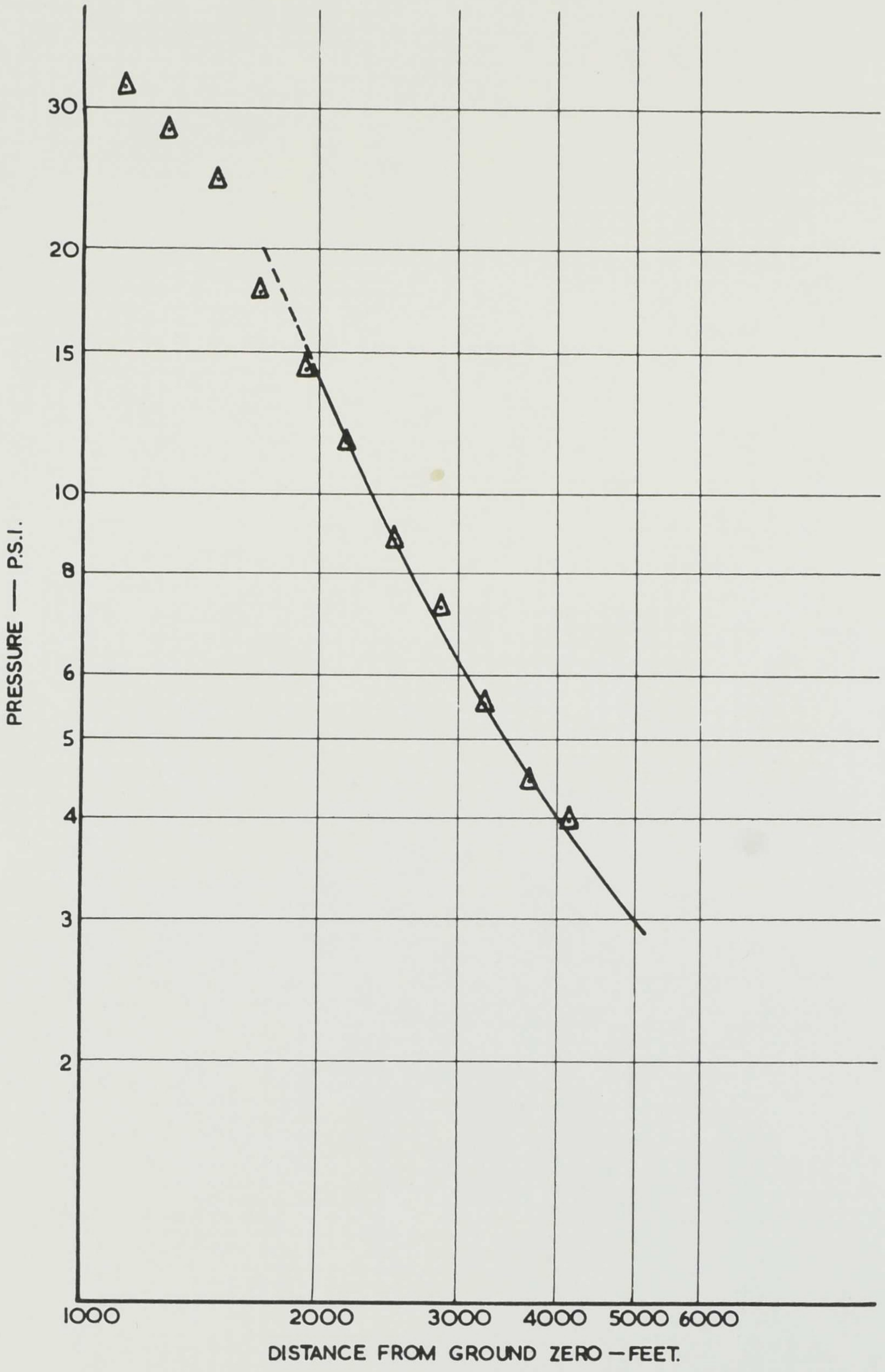

FIG. 37. ROUND 4.-PRESSURE/DISTANCE CURVE F.M.T. RESULTS.

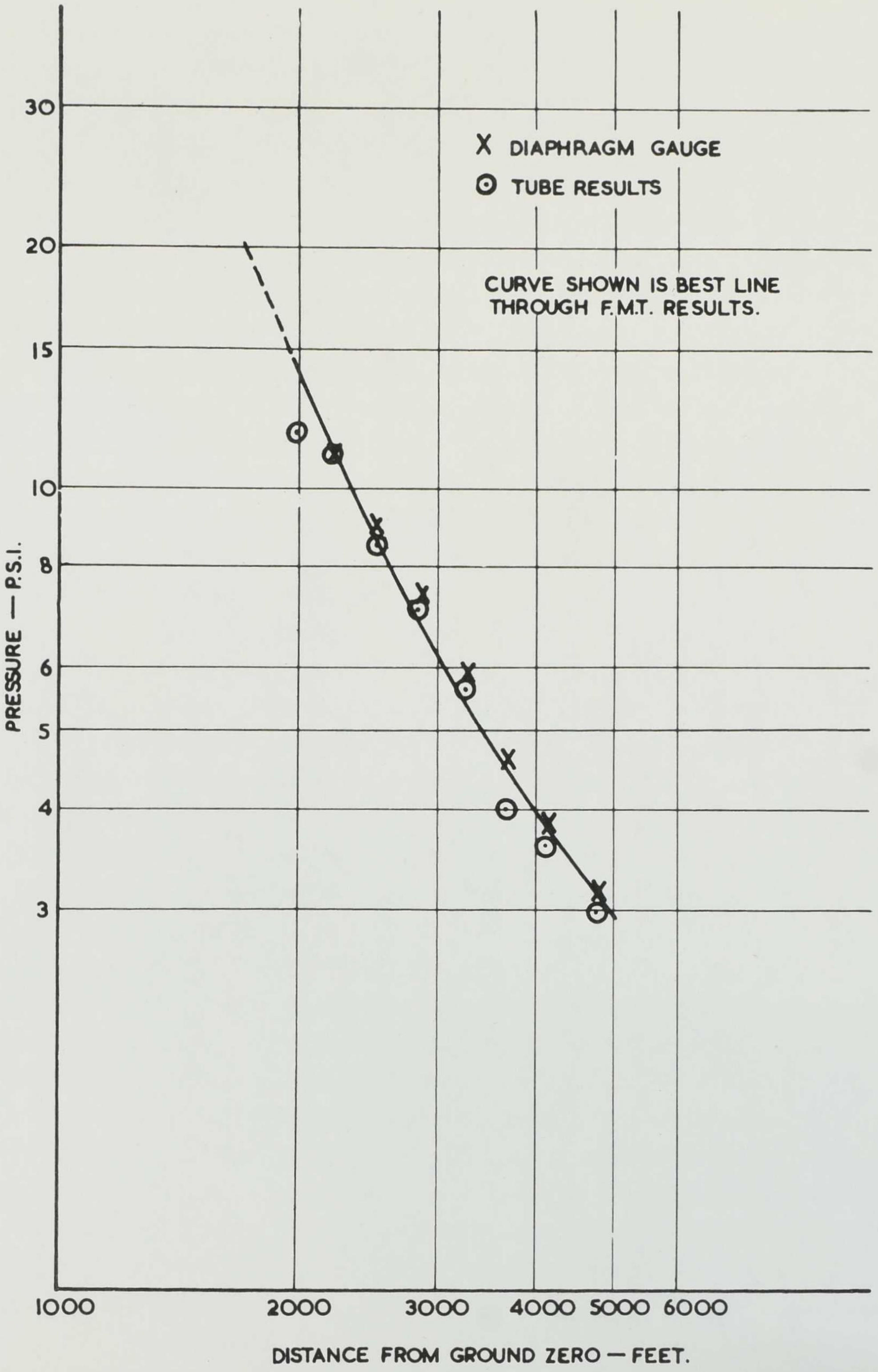

FIG. 38. ROUND 4. – PRESSURE/DISTANCE CURVE. DIAPHRAGM & TUBE RESULTS.

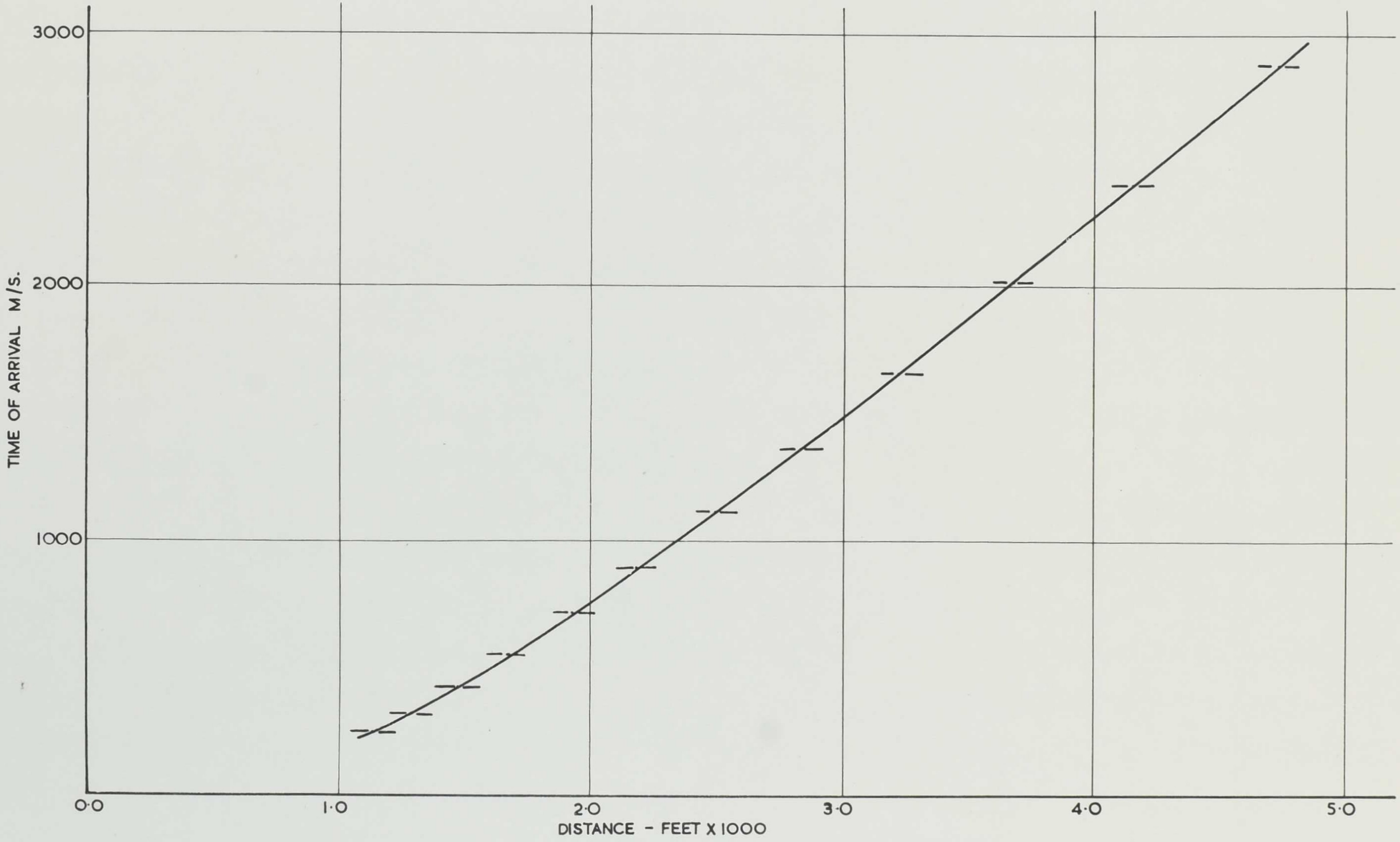

FIG. 39. ROUND 4. — DISTANCE/TIME CURVE.

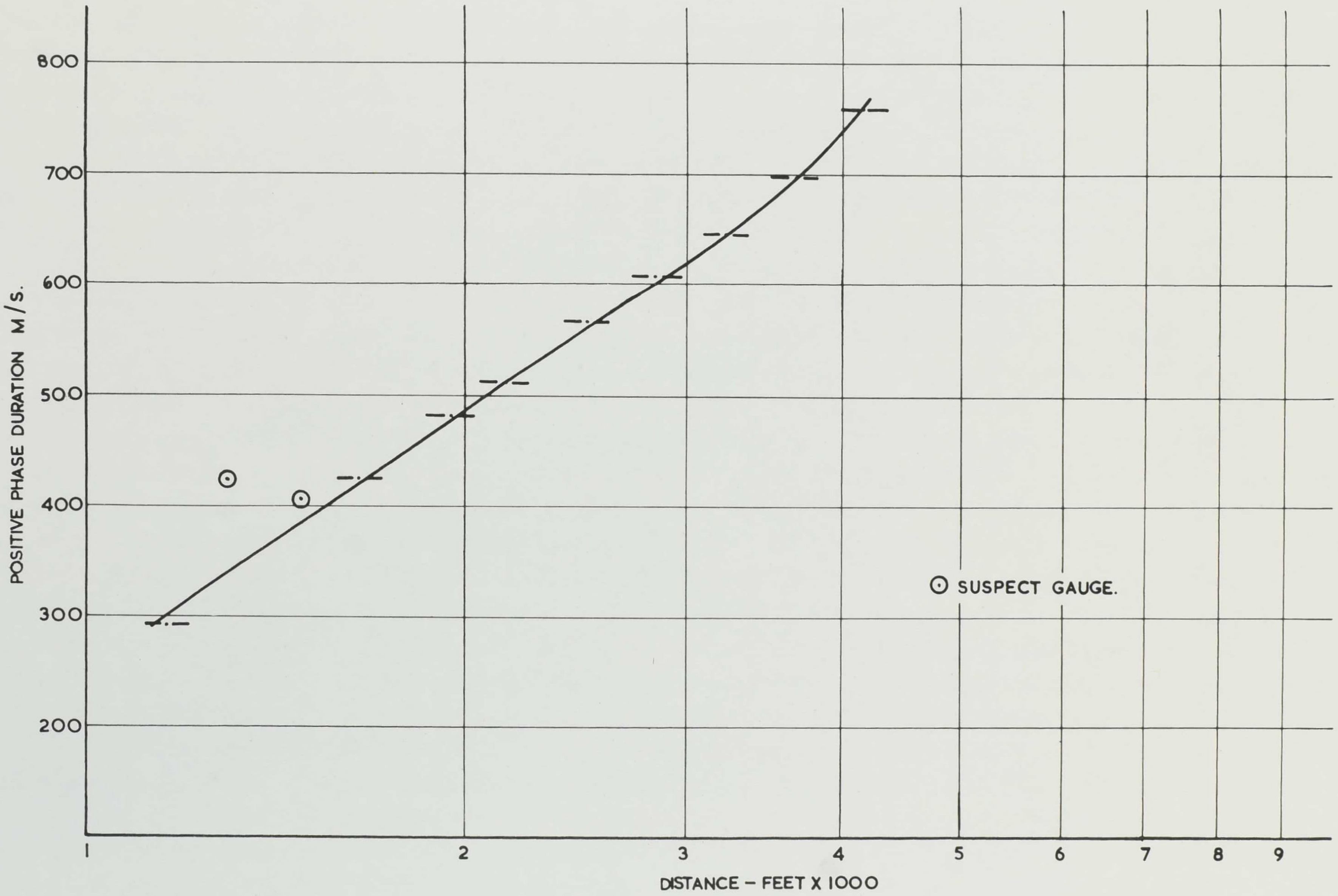

FIG. 40. ROUND 4.— DISTANCE / PHASE DURATION CURVE.

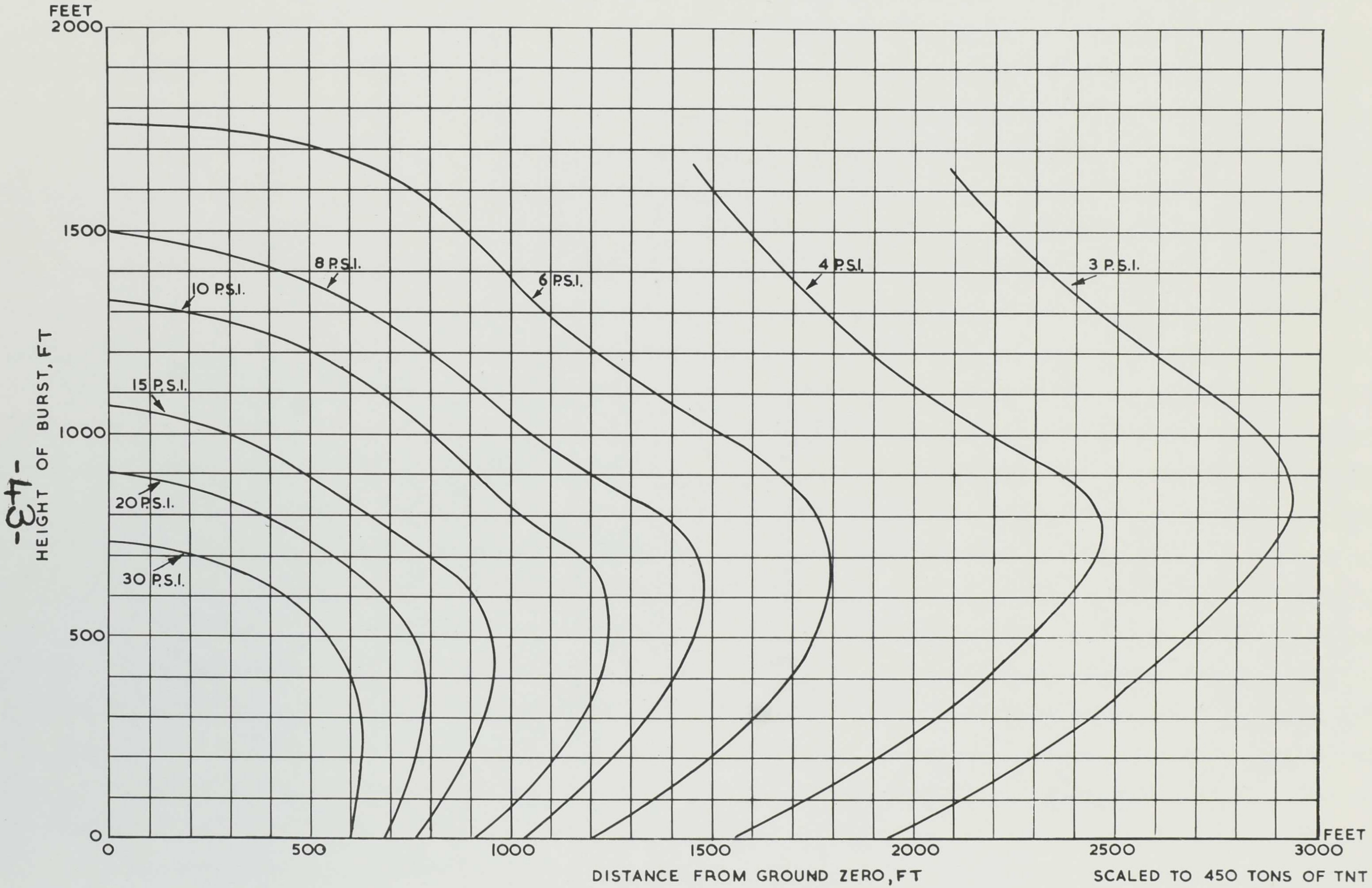

FIGURE 41. HEIGHT OF BURST: PRESSURE / DISTANCE DATA FOR 450 TONS OF T.N.T.

Initial Distribution

Internal

No. 1	DAWRE, Sir William Penney
2	DDAWRE, Mr. W. R. J. Cook
3	CR, Mr. C. A. Adams
4	CWD, Mr. E. F. Newley
5	Declassification Officer, Dr. A. H. Davis
6	SSFD, Mr. E. F. Mott
7	SSPD, Dr. J. Corner
8	SSTD, Mr. R. Pilgrim
9	DSSF, Mr. C. L. Farror
10	SPT, Mr. J. T. Tomblin
11	SWP, Mr. E. P. Hicks
12	Mr. P. J. Atkins, SPT
13	Mr. I. Ll. Davies, DSSF
14	Dr. W. G. P. Lamb, DSSF
15	Mr. H. G. MacPherson, DSSF
16	Mr. A. C. Purdie, DSSF
17	Mr. S. A. Reavill, SPT
18	Mr. N. J. Rees, DSSF
19	Mr. D. E. J. Samuels, DSSF
20	Mr. G. C. Scorgie, SWP
21	Mr. N. S. Thumpston, DSSF
22	Mr. R. G. Turner, DSSF
23	Mr. G. R. Warren, DSSF
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War Office

29-32	Scientific Adviser to the Army Council (Mr. P. Johnson) and for Mr. E. R. Drake Seager

Air Ministry

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34	Director General of Atomic Weapons (Mr. E. S. Jackson)

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35	Mr. V. H. B. Macklen

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